

Research Article

The Evolution of Artificial Intelligence Research in Autonomous Vehicles (2015–2025): A Bibliometric and Thematic Review

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Abstract: This study presents a comprehensive bibliometric and thematic review of artificial intelligence (AI) research in the domain of autonomous vehicles (AV) over the period 2015–2025. Based on 856 academic publications indexed in the Web of Science (WoS) database, the analysis utilizes VOSviewer and Excel to map publication trends, citation dynamics, collaborative networks, keyword co-occurrences, and bibliographic coupling. Furthermore, content analysis of the top 25 most-cited articles reveals dominant research themes and methodological approaches. The findings show a substantial surge in publication volume and scholarly impact after 2019, with core attention given to deep learning, planning algorithms, Industry 4.0 integration, and intelligent transportation systems. The United States, China, and the United Kingdom lead in research output and global collaborations. However, the study identifies a disciplinary imbalance, with ethical, regulatory, and societal dimensions significantly underrepresented. By combining quantitative bibliometric methods with qualitative thematic insights, this review provides a holistic overview of the evolution of AI-powered autonomous mobility and proposes conceptual and methodological directions for future research. The study offers valuable guidance for academics, policymakers, and industry stakeholders seeking to navigate the rapidly transforming landscape of autonomous vehicle technologies.

Keywords: Autonomous Vehicles, Artificial Intelligence, Bibliometric Analysis, Thematic Analysis, Intelligent Transportation Systems, VOSviewer

Otonom Araçlarda Yapay Zekâ Araştırmalarının Evrimi (2015–2025): Bibliyometrik ve Tematik Bir İnceleme

Özet: Bu çalışma, 2015–2025 döneminde otonom araçlar (OA) alanındaki yapay zekâ (YZ) araştırmalarını kapsamlı bir bibliyometrik ve tematik incelemeyle ele almaktadır. Web of Science (WoS) veri tabanında dizinlenen 856 akademik yayına dayanan analizde, yayın eğilimleri, atıf dinamikleri, iş birliği ağları, anahtar kelime eş-oluşumları ve bibliyografik eşleşmeler VOSviewer ve Excel programları kullanılarak haritalanmıştır. Ayrıca, en çok atıf alan 25 makale üzerinden yapılan içerik analizi, baskın araştırma temaları ve metodolojik yaklaşımları ortaya koymaktadır. Bulgular, 2019 sonrası yayın hacmi ve akademik etki açısından dikkate değer bir artış olduğunu ve derin öğrenme, planlama algoritmaları, Endüstri 4.0 entegrasyonu ve akıllı ulaşım sistemlerine yoğunlaşan bir ilgi bulunduğunu göstermektedir. Amerika Birleşik Devletleri, Çin ve Birleşik Krallık, araştırma çıktıları ve küresel iş birliklerinde başı çekmektedir. Ancak, etik, düzenleyici ve toplumsal boyutların belirgin biçimde yeterince temsil edilmediği disiplinler bir dengesizlik tespit edilmiştir. Nicel bibliyometrik yöntemleri nitel tematik analizle birleştiren bu inceleme, YZ destekli otonom mobilitenin evrimine bütüncül bir bakış sunmakta ve gelecekteki araştırmalar için kavramsal ve metodolojik öneriler getirmektedir. Çalışma, hızla dönüşen otonom araç teknolojileri alanında yön bulmak isteyen akademisyenler, politika yapımcılar ve sektör temsilcileri için değerli bir rehber niteliği taşımaktadır.

Anahtar Kelimeler: Otonom Araçlar, Yapay Zekâ, Bibliyometrik Analiz, Tematik Analiz, Akıllı Ulaşım Sistemleri, VOSviewer

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1. Introduction

AV are systems that perceive their environment, make decisions, and operate without human input—transforming transportation fundamentally. At the core of this transformation lies artificial intelligence, with subfields such as machine learning, deep learning, computer vision, and decision support systems playing a pivotal role in enhancing autonomous driving capabilities. Today, AI-enabled autonomous systems are not limited to technical advancements alone; they also generate significant societal and economic impacts in areas such as safety (Kim & Duffy, 2021; Sharma & Rana, 2024), sustainability (Beck et al., 2022), smart city infrastructure (Othman, 2022), and crisis management (Zhou et al., 2024). Especially in the aftermath of the COVID-19 pandemic, the adoption of robotic systems and autonomous technologies has accelerated, leading to a marked increase in academic interest in AV (Li et al., 2025).

The technical infrastructure of AV is structured in a three-layer architecture (Bathla et al., 2022):

1. Perception Layer: Fusion of raw data from LIDAR, radar, cameras, and ultrasonic sensors.
2. Decision Layer: Processing environmental data through deep learning models (e.g., YOLOv8, Transformer networks) for route planning and risk assessment.
3. Action Layer: Execution of commands via the electronic control unit (ECU) to the steering, braking, and acceleration systems.

This architecture enables sensor data to be processed with latency below 200 milliseconds, thereby supporting real-time responsiveness. Consequently, path planning, decision-making, and motion control are executed efficiently and safely (Jingyuan, 2023; Khan et al., 2022; Liu et al., 2020; Bathla et al., 2022).

Compared to human drivers, AV can prevent many accidents and reduce injury severity in the event of collisions. The critical importance of predicting and mitigating traffic accidents is also highlighted in traditional traffic research using machine learning, as demonstrated in the context of Türkiye by Korkmaz (2023). This underscores the broader potential of AI, not only in autonomous systems but also in enhancing our understanding of conventional road safety challenges. However, most accidents involving AV during test phases stem from the unpredictable behaviour of other road users. To improve safety, AV must enhance their ability to perceive environmental risks and make proactive decisions (Wang et al., 2020; Zhou, 2024).

The safe operation of AV relies heavily on Vehicle-to-Everything (V2X) communication technologies. V2X facilitates real-time data exchange between vehicles (V2V), infrastructure (V2I), pedestrians (V2P), and networks (V2N). It supports coordination in traffic congestion, intersections, and emergency braking, potentially reducing accidents by 30%–50% (Khan et al., 2022).

AV has the potential to reduce traffic accidents, transform urban environments, and introduce innovations in public transportation. However, ethical decision-making (e.g., prioritizing passengers vs. pedestrians), insurance, legal regulations, and public acceptance remain contentious issues. While society tends to support AV that prioritize the public good in theory, individuals often prefer vehicles that ensure their own safety in practice (Hussain & Zeadally, 2019; Rojas-Rueda et al., 2020; Bonnefon et al., 2015; Othman, 2022; Bartneck et al., 2020).

AV constitutes a critical component of the digital transformation spanning from production to transportation. They are part of a broader ecosystem of autonomous systems, which also includes unmanned aerial vehicles (UAVs) used for environmental monitoring and other smart city applications (Ergunşah & Koşunalp, 2022). The synergy between ground-based AV and aerial UAVs promises a more comprehensive and intelligent approach to urban management and logistics. The process known as Industry 4.0 aims to establish smart factories and interconnected ecosystems through cyber-physical systems, the Internet of Things (IoT), and cloud computing (Kagermann et al., 2013). Within this ecosystem, AV serves as one of the foundational elements of Industry 4.0 by contributing to supply chain optimization, smart city infrastructure, and autonomous logistics solutions via real-time data sharing (Bathla et al., 2022).

AV are applied across various domains, including automobiles, buses, trucks, and racing vehicles, and offer innovative solutions in supply chains, urban mobility, and pandemic response. In the future, safer, more efficient, and socially integrated AV systems will depend heavily on the integration of AI, IoT, and cloud/fog computing (Bathla et al., 2022; Liu et al., 2019; Betz et al., 2022).

Since 2015, thousands of journal articles, conference proceedings, and book chapters have been published on the integration of AV and AI. Research has primarily focused on subfields such as machine learning, deep learning, and robotic vehicles. The countries and institutions with the highest publication output have played a key role in shaping global research performance (Mudhivarthi & Thakur, 2022; Luan et al., 2022; Babaei et al., 2025).

The primary function of AI in AV is to perceive and analyze environmental data and make decisions accordingly. Machine learning and computer vision techniques are widely used in this process. For instance, deep learning-based visual recognition algorithms like YOLOv8 are employed for real-time detection, enabling vehicles to identify road conditions, other vehicles, pedestrians, and obstacles rapidly and accurately (Mostafa, 2024; Çetaş, 2024).

The main application areas of AI in AV include perception, localization and mapping, planning, and decision-making. At the algorithmic level, convolutional neural networks (CNNs) are prominent in perception and mapping, while deep reinforcement learning dominates planning and decision-making (Babaei et al., 2025; Ma et al., 2020; Sharma & Rana, 2024; Garikapati & Shetiya, 2024).

In recent years, academic research on AV and AI has gained momentum, resulting in increased publication output and the emergence of diverse thematic trends and interdisciplinary interactions. Bibliometric analyses indicate that AI is the main driver of knowledge innovation in AV and that research is predominantly focused on technological advancements. However, integration with the social sciences remains limited (Huang et al., 2023; Luan et al., 2022). Despite this, there is a notable lack of comprehensive studies that systematically map the literature and analyze thematic patterns at the content level.

While the application of AI in autonomous vehicles is a widely researched topic, a limited number of studies have attempted to map this field through bibliometric analysis. Existing bibliometric reviews (e.g., Huang et al., 2023; Luan et al., 2022; Mudhivarthi & Thakur, 2022) have provided valuable foundational insights, often with a narrower scope—focusing, for instance, on specific sub-fields like robotic vehicles or a more limited timeframe. However, these studies have largely remained at the quantitative level. This study distinguishes itself from existing literature in three key ways: First, it offers a more comprehensive temporal coverage (2015-2025), capturing the most recent evolutionary trends, including the post-pandemic surge in research. Second, and most critically, it moves beyond a purely quantitative bibliometric description by integrating a qualitative thematic analysis of the most influential publications. This mixed-methods approach allows for not only the mapping of the intellectual structure but also an in-depth exploration of the dominant research themes, methodological approaches, and conceptual content at the core of the field. Third, it explicitly identifies and discusses the disciplinary imbalance between technical and social sciences, proposing concrete interdisciplinary research directions. Therefore, the unique contribution of this review is to provide a holistic, multi-dimensional overview of the AI-AV research landscape, bridging the gap between quantitative trends and qualitative insights, and offering a forward-looking perspective that guides future research both technically and societally.

In this context, the present study aims to examine academic publications on AV and AI published in the Web of Science (WoS) database between 2015 and 2025 through a combined approach of bibliometric and qualitative content analysis. The study seeks to uncover research trends, collaboration structures, and thematic developments in the field by evaluating publication dynamics, citation structures, author and country-level analyses, keyword patterns, and the thematic content of the most-cited articles. The bibliometric findings (see Section 4.6) reveal that concepts such as Industry 4.0 and V2X hold central positions in the keyword co-occurrence networks. In particular, the "connected vehicles" and "smart factory" clusters in Figure 10 reflect the technical integration of these concepts within the AV literature.

2. Materials and methods

2.1. Research Objective

In this study, a bibliometric analysis was conducted on July 9, 2025, using the Web of Science (WoS) database to understand the evolution and impact of AI in AV research between 2015 and 2025. The temporal scope (2015-2025) was selected to capture the complete modern evolution of AI in AV, starting from the period when key enabling technologies (e.g., deep learning) reached sufficient maturity and leading up to the most recent trends to ensure contemporary relevance. The aim of the study is to contribute to the field and provide a conceptual foundation for future research.

This study seeks to answer the following research questions:

1. What is the annual distribution and publication type of AI-related studies on autonomous vehicles indexed in WoS between 2015 and 2025?
2. How does citation count of these publications vary annually?
3. Who are the most frequently collaborating authors based on co-authorship analysis?
4. What are the citation patterns of individual authors in AV and AI research?
5. What are the citation trends based on countries of publication?
6. What are the key patterns in author keyword usage?
7. What are the bibliographic coupling patterns of the documents?
8. What are the co-citation relationships among cited authors?
9. What themes emerge from the content analysis of the top 25 most-cited articles?

2.2. Research Method

This study employs an integrated methodology combining bibliometric analysis and content analysis to reveal scientific trends. Bibliometric analysis offers a quantitative view of scientific output (Pritchard, 1969) and has been effectively applied to map research trends in various emerging technological fields, including education (Talan, 2021). In this study, key techniques such as co-citation, co-authorship, and keyword co-occurrence analyses were performed using VOSviewer (Van Eck & Waltman, 2010).

Content analysis refers to the systematic categorization and interpretation of qualitative data (Krippendorff, 2018). In this study, content analysis was carried out in two phases: thematic coding (Braun & Clarke, 2006) and concept mapping (Novak & Cañas, 2008). This combined qualitative approach is well-established for extracting underlying themes from a body of literature, as demonstrated in meta-analytic and thematic studies in other domains (Batdı & Talan, 2019). During data collection, publications between 2015 and 2025 were retrieved from WoS using the keywords “autonomous vehicles” and “AI.” Duplicates and irrelevant records were removed to create the final dataset.

For analysis, VOSviewer 1.6.20 was used for bibliometric evaluation, while Microsoft Excel supported the qualitative thematic coding. This integrated methodological framework enabled a comprehensive exploration of both the quantitative and qualitative dimensions of AI-related AV research.

The study focuses on the period from 2015 to 2025. The year **2015** was selected as the starting point as it marks a pivotal moment following key foundational developments, such as the public demonstration of advanced self-driving prototypes and the increased maturity of deep learning algorithms (e.g., the rise of Convolutional Neural Networks for vision tasks), which catalyzed a new wave of academic and industrial research in AI-powered autonomous vehicles. The endpoint of **2025** was chosen to provide the most up-to-date and comprehensive overview of the literature, capturing the most recent evolutionary trends and ensuring the study's contemporary relevance. This eleven-year window effectively captures the entire modern lifecycle of the field, from its accelerated growth phase to its current state as a mature research domain.

The bibliometric analysis was conducted to examine the existing body of research on AI in autonomous vehicles. On July 9, 2025, a search was performed in the WoS database using the query: "autonomous vehicles" OR "AV" (Topic) AND "AI" OR "AI" (Author Keywords) AND English (Language) AND 2015–2025 (Year Published).

This search yielded 856 results. The terms “AI” and “AI” were specifically included to focus on the role of AI. Duplicate entries were removed through manual inspection. The earliest publication dated back to 2015, while the most recent was from 2025. The dataset was downloaded in a format compatible with analysis tools. Predefined bibliometric techniques were applied using VOSviewer 1.6.20, and visualizations were generated accordingly.

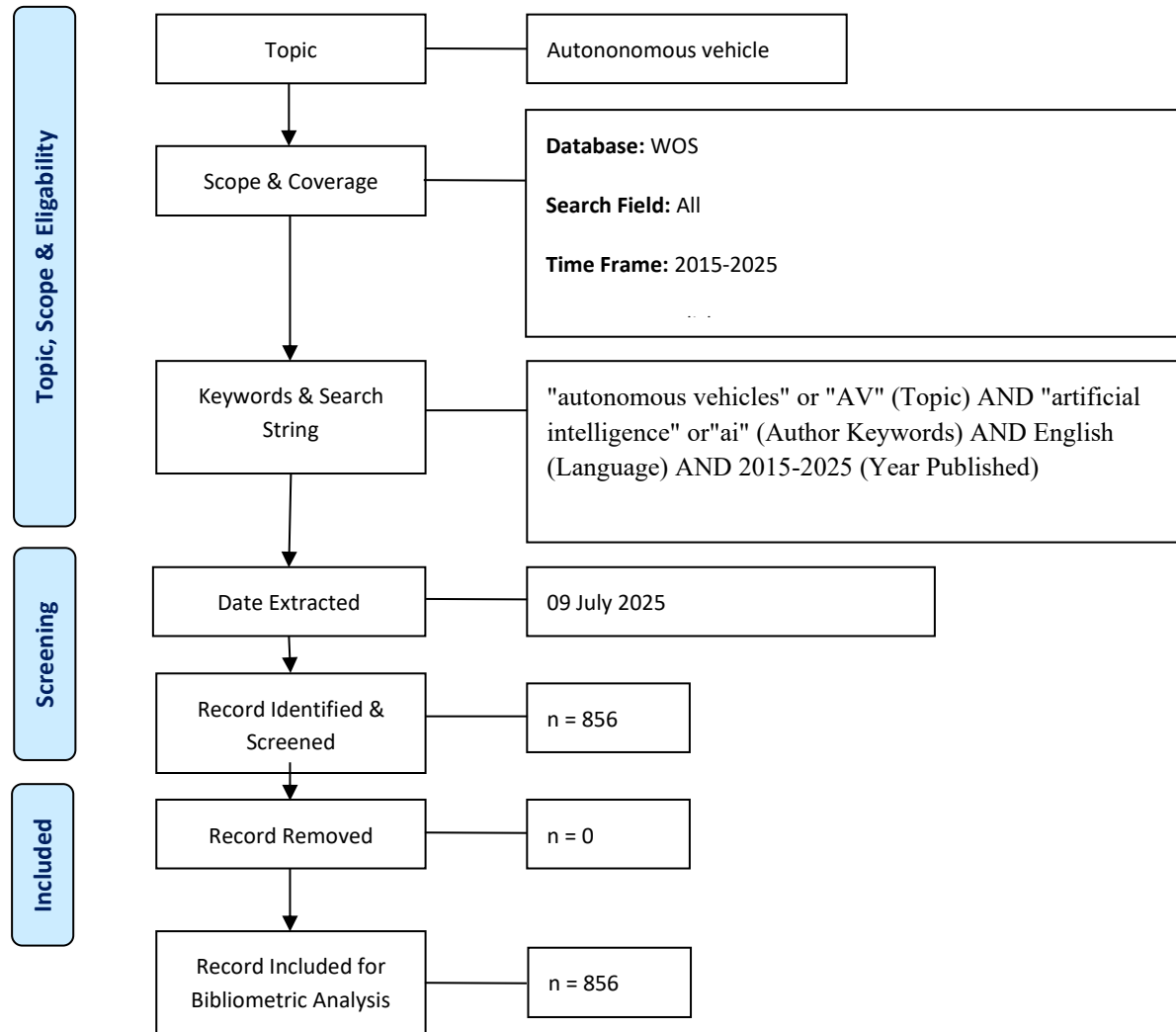


Figure 1. Flow diagram of the search strategy.

Figure 1 illustrates the stages of the bibliometric analysis conducted for this study. In the first stage, data were retrieved from the Web of Science (WoS) database using predefined keywords. In the second stage, the dataset was imported into the VOSviewer software, where the specified bibliometric analyses were performed. Subsequently, content analysis was conducted using Microsoft Excel to identify thematic structures. In the final stage, trends and themes were synthesized to develop the discussion and conclusion sections of the study.

3. Results

3.1. Annual Distribution and Publication Types

A total of 856 publications related to AI in AV were identified in the Web of Science (WoS) database between 2015 and 2025. These publications were authored by 3,050 researchers, affiliated with 1,405 institutions across 92 countries. The studies were published in 87 different academic journals.

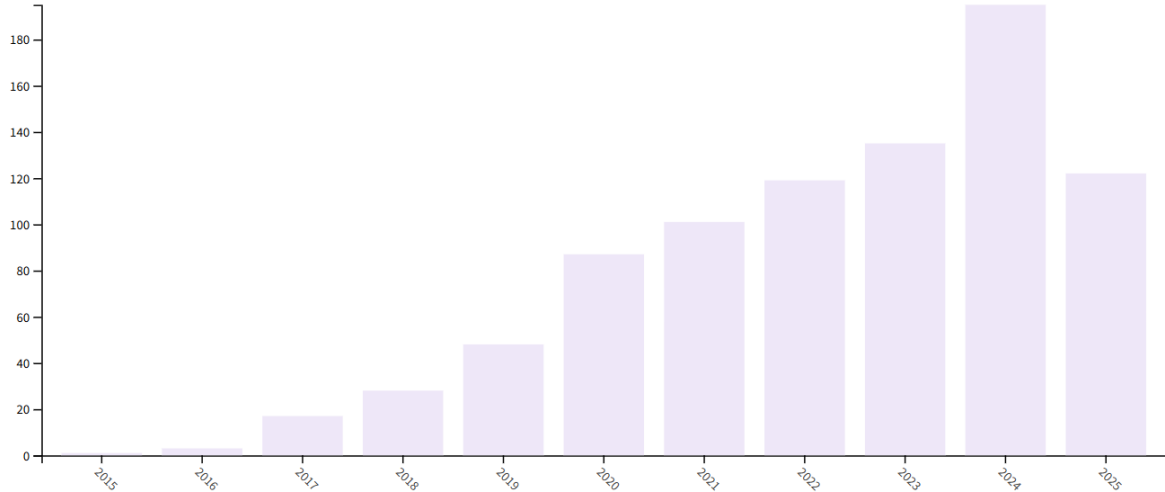


Figure 2. Annual distribution of publications on AI in AV (2015–2025).

An examination of Figure 2 reveals that the number of publications, which was only 1 in 2015, began to increase significantly starting in 2019. This growth indicates that, like other fields, research involving AI in the context of AV has expanded rapidly. In the following years, the publication volume continued to rise, reaching a peak of 195 publications in 2024. Based on the upward trend observed in the graph, it is expected that the number will continue to increase in 2025 as well.

Select All ☐	Field: Document Types	Record Count	% of 856
☐	Article	556	64.953%
☐	Proceeding Paper	224	26.168%
☐	Review Article	68	7.944%
☐	Early Access	18	2.103%
☐	Editorial Material	8	0.935%
☐	Book Chapters	3	0.350%
☐	Correction	1	0.117%
☐	Letter	1	0.117%
☐	Retracted Publication	1	0.117%

Figure 3. Types of publications on AI in AV research.

An analysis of Figure 3 reveals that among the 856 publications, 556 are journal articles, 224 are conference proceedings, 68 are review articles, 18 are early access papers, 8 are editorial materials, 3 are book chapters, and there is one publication each in the categories of correction, letter, and retracted publication. These documents are indexed across various WoS categories: 442 in SCI-Expanded, 223 in CPCI-S (Conference Proceedings Citation Index–Science), 125 in ESCI (Emerging Sources Citation Index), 124 in SSCI (Social Sciences Citation Index), 13 in CPCI-SSH (Social Sciences & Humanities), 5 in A&HCI (Arts & Humanities Citation Index), and 1 in BKCI-SSH (Book Citation Index–Social Sciences & Humanities).

According to Figure 4, the top five countries in terms of publication output are: the United States (227 publications), China (137), the United Kingdom (74), South Korea (56), and Germany (52). These are followed closely by Canada (51), India (51), and Australia (47).

Select All ☐	Field: Countries/Regions	Record Count	% of 856
☐	USA	227	26.519%
☐	PEOPLES R CHINA	137	16.005%
☐	ENGLAND	74	8.645%
☐	SOUTH KOREA	56	6.542%
☐	GERMANY	52	6.075%
☐	CANADA	51	5.958%
☐	INDIA	51	5.958%
☐	AUSTRALIA	47	5.491%
☐	FRANCE	41	4.790%
☐	ITALY	34	3.972%

Figure 4. Number of publications by country in AI and AVresearch (2015–2025).

An analysis of Figure 5 shows the Web of Science subject categories of the publications. The most frequently represented fields include Electrical and Electronic Engineering (302 publications), Computer Science—Information Systems (165), Telecommunications (145), Computer Science—AI (138), Transportation Science and Technology (119), Computer Science—Theory and Methods (100), Computer Science—Interdisciplinary Applications (59), Civil Engineering (47), and Multidisciplinary Engineering (43). These results indicate that the majority of research is concentrated in the fields of engineering and computer science.



Figure 5. Web of Science subject categories of the publications.

3.2. Citation Trends by Year

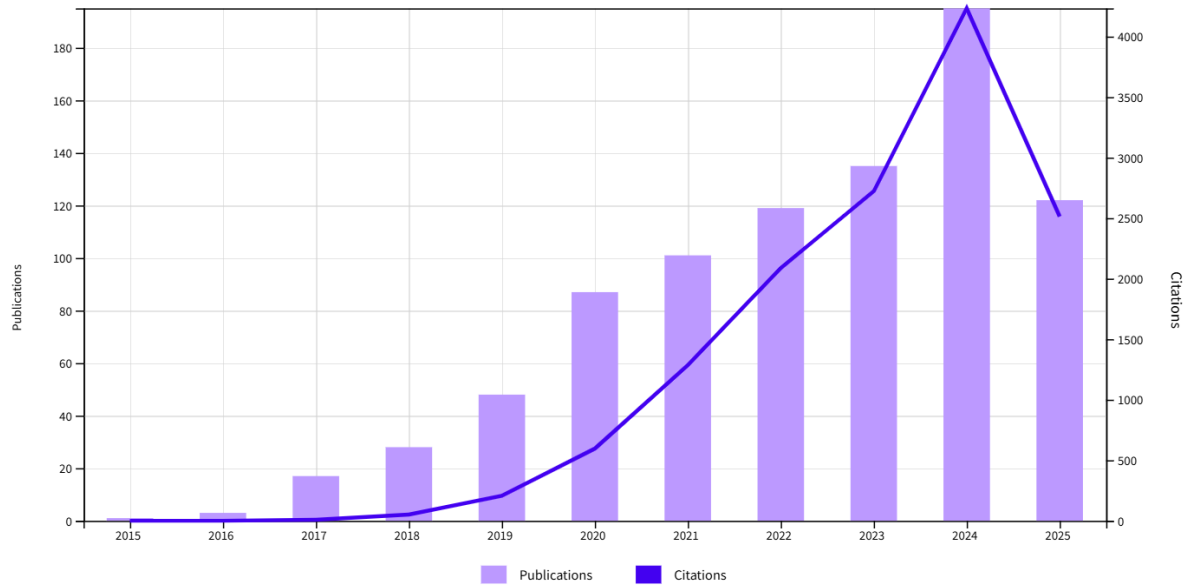


Figure 6. Annual citation counts for publications on AI in AV (2015–2025).

Table 1. Most Cited Publications in AI and AVResearch (2015–2025)

Number	Publication Year	Publication Name	Authors	Total number of citations
1	2018	Planning and Decision-Making for Autonomous Vehicles	Schwarting, W; Alonso-Mora, J and Rus, D	559
2	2016	Applied AI and trust-The case of autonomous vehicles and medical assistance devices	Hengstler, M; Enkel, E and Duelli, S.	410
3	2020	From high-touch to high-tech: COVID-19 drives robotics adoption	Zeng, ZJ; Chen, PJ and Lew, AA	347
4	2020	Mobile Edge Intelligence and Computing for the Internet of Vehicles	Zhang, J and Letaief, KB	347
5	2020	AI applications in the development of autonomous vehicles: a survey	Ma, YF; Wang, ZY; (...); Yang, L	333
6	2020	Survey of Deep Reinforcement Learning for Motion Planning of Autonomous Vehicles	Ma, YF; Wang, ZY; (...); Yang, L	328
7	2022	Understanding AI adoption in manufacturing and production firms using an integrated TAM-TOE model	Chatterjee, S; Rana, NP; (...); Baabdullah, AM	324
8	2019	The strategic role of logistics in the industry 4.0 era	Tang, CS and Veelenturf, LP	301
9	2019	Applications of AI in Transport: An Overview	Abduljabbar, R; Dia, H; (...); Bagloee, SA	255
10	2017	Data Fusion and IoT for Smart Ubiquitous Environments: A Survey	Alam, F; Mehmood, R; (...); Albeshri, A	235

An analysis of Figure 6 reveals the annual citation trends. In 2019, the number of citations was 206, which increased to 596 in 2020. This upward trajectory continued with 1,286 citations in 2021, 2,087 in 2022, 2,723 in 2023, and reaching 4,233 citations in 2024. This steady growth reflects the rapid expansion of research related to AI. The trend is clearly visualized in the accompanying graph, confirming the acceleration of academic impact in this domain.

Table 1 presents the ten most highly cited publications. The article titled "Planning and Decision-Making for Autonomous Vehicles" by Schwarting, W.; Alonso-Mora, J.; and Rus, D. has received a total of 559 citations (Schwarting et al., 2018). The second most cited paper, "Applied AI and Trust—The Case of Autonomous Vehicles and Medical Assistance Devices" by Hengstler et al. (2016), has been cited 410 times. The third, "From High-Touch to High-Tech: COVID-19 Drives Robotics Adoption" by Zeng et al. (2020), received 347 citations, rounding out the top three most influential articles.

3.3. Co-authorship of Authors

A co-authorship network map was generated based on the criteria of at least one publication and one citation per author, in order to identify the most collaborative and interconnected researchers in the field. The analysis revealed 9 distinct clusters comprising 77 authors. A total of 304 links and a total link strength of 352 were recorded among the authors with the strongest co-authorship connections.

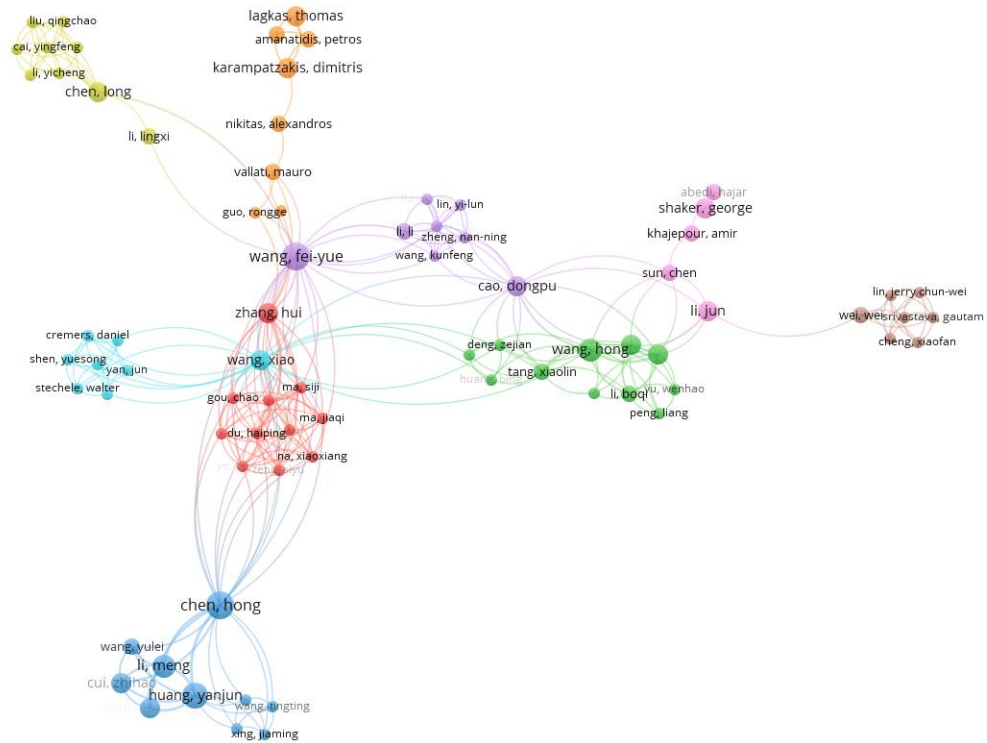


Figure 7. Co-authorship network of authors (minimum one publication and one citation, ranked by highest total link strength).

According to Figure 7, the most cited author within the given clusters is Wang Fei-Yue, with 6 publications and 218 citations. Zhang Jiliang follows with 3 publications and 214 citations, while Ahn Sung-Hoon has received 205 citations from a single publication. However, when examining the strength of co-authorship links, the most connected author is Chen Hong from the blue cluster, with 6 publications and 34 citations. He is followed by Wang Fei-Yue in the purple cluster and Wang Xiao in the turquoise cluster, who has 3 publications and 145 citations. This indicates that the most prolific author is not necessarily the most connected one.

Figure 7 presents a co-authorship network visualizing the collaborative structure among researchers in the field. Each node represents an author, while the edges indicate co-authored publications. The graph

reveals several distinct clusters, each corresponding to closely collaborating research groups. Notably, *Wang Fei-Yue* emerges as a central figure with extensive inter-cluster connections, suggesting a bridging role across multiple research domains. Authors such as Zhang Hui, Wang Xiao, and Chen Hong also demonstrate high centrality, indicative of their prominent positions within their respective clusters. The presence of peripheral nodes, such as Shaker George and Lin Jerry Chun-Wei, may reflect occasional contributors or international collaborators. The modular structure of the network underscores the fragmented yet interconnected nature of research activities in this domain. Such patterns highlight both the disciplinary diversity and the pivotal role of key scholars in facilitating knowledge exchange and collaboration.

3.4. Citation of Authors

To identify citation networks, an author citation analysis network map was generated using the criteria of at least one publication and at least one citation. The analysis, conducted on 980 interconnected units, revealed a total of 28 clusters, 711 observation units, 3,934 links, and a total link strength of 4,242.

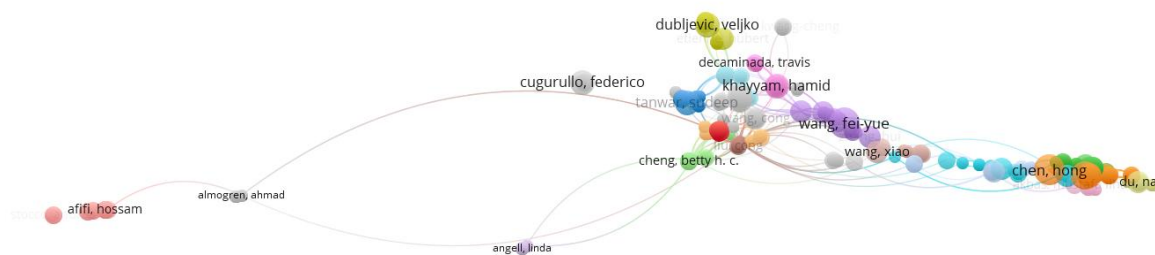


Figure 8. Citation of Authors (minimum 1 publication and 1 citation, ranked by highest link strength)

According to Figure 8, Ma Yifang, Wang Zhenyu, Yang Hong, and Yang Lin have the highest link strength, each with only one publication and 333 citations. They are followed by Duelli Selina, Enkel Ellen, and Hengstler Monika, who also have one publication and 410 citations. Based on the citation counts, it appears that the authors in each group co-authored the same paper.

Figure 8 illustrates a co-authorship network that reveals a relatively decentralized collaboration structure. Unlike densely clustered graphs, this network is characterized by a more linear and sparse distribution, with fewer highly interconnected author groups. Wang Fei-Yue, Chen Hong, and Khayyam Hamid appear as the central nodes, forming the backbone of the network and connecting several smaller research clusters. Peripheral authors, such as Afifi Hossam, Almogren Ahmad, and Angel Linda, are loosely connected, reflecting limited or one-time collaborative engagements. The presence of such extended connections suggests an expanding field with emerging interdisciplinary efforts. This structure may indicate either a developing research area or one where collaboration remains relatively siloed, with a few key individuals facilitating broader integration.

3.5. Citation of Countries

To generate a network map based on the citations received by publications from their countries of origin, an analysis was conducted using the criteria of at least one publication and one citation per country. The analysis, performed on 56 interconnected observation units, identified 11 clusters, 325 links, and a total link strength of 746.

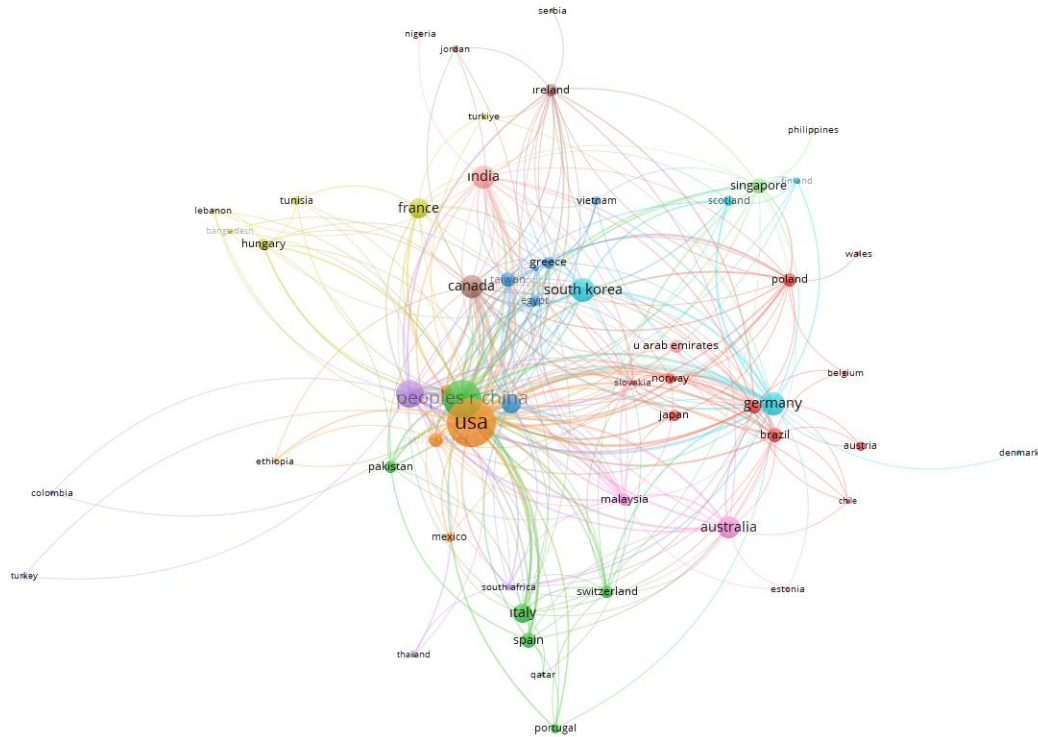


Figure 9. Citation of Countries (minimum 1 publication and 1 citation, ranked by highest link strength).

According to Figure 9, the countries with the highest number of citations are the USA (4,800 citations), China (2,989 citations), the United Kingdom (1,779 citations), and Australia (1,059 citations). These countries also rank in the top four in terms of total link strength. However, when ranked by total link strength, the order is: USA (222), China (175), the United Kingdom (117), and Germany (88). In terms of the number of publications, the top five countries are: USA (227 publications), China (137 publications), the United Kingdom (74 publications), South Korea (56 publications), and Germany (52 publications).

Figure 9 illustrates a global collaboration network based on co-authorship between countries. The United States (USA), China (People's Republic of China), and Germany emerge as central hubs with the highest number of international linkages, reflecting their leading roles in global research output and scientific influence. Dense interconnections are observed between the USA and several countries, including Canada, South Korea, the United Kingdom, and Germany, indicating strong transnational research partnerships. Similarly, China maintains substantial collaborative ties, particularly with Australia, Singapore, and European countries. Countries like India, France, and Italy also exhibit active roles, positioned relatively centrally in the network. In contrast, nations such as Turkey, Colombia, and Ethiopia are located more peripherally, suggesting a lower volume of international collaborations or more regionally focused partnerships. The network reveals a highly interconnected global research landscape, where knowledge production is increasingly dependent on cross-border cooperation.

3.6. Co-occurrence of Author Keywords

An analysis was conducted on 311 interconnected observation units that included keywords appearing at least three times. The results revealed a total of 15 clusters, 4,431 links, and a total link strength of 7,707.

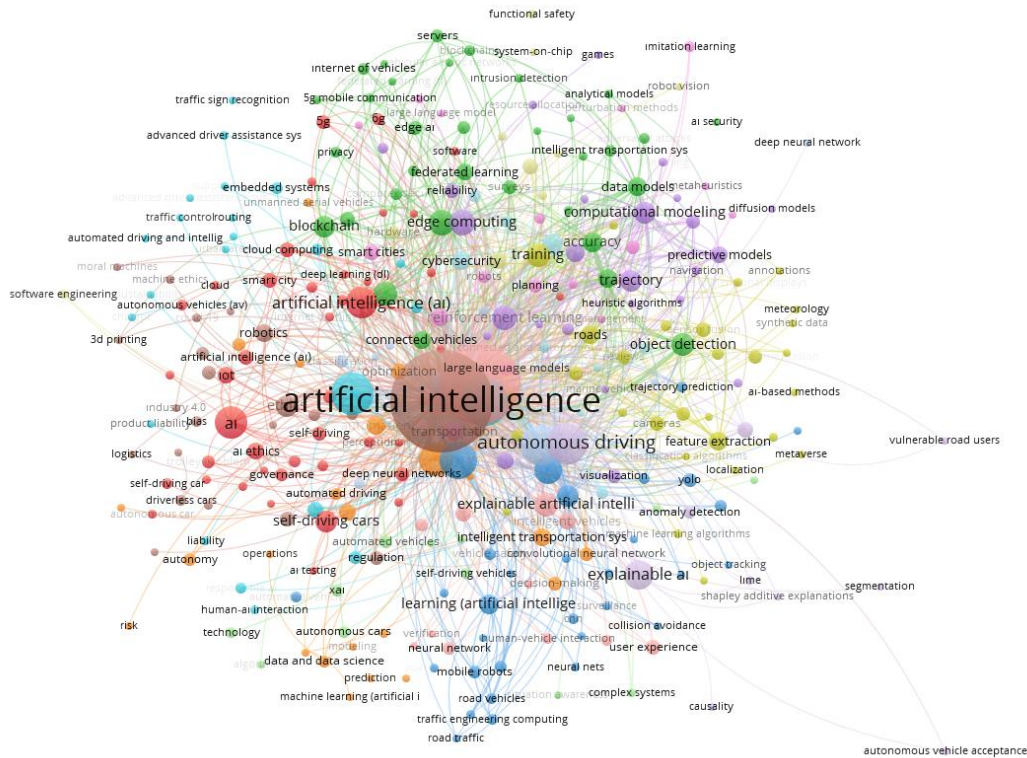


Figure 10. Co-occurrence of Author Keywords (minimum 3 occurrences, ranked by highest link strength).

According to Figure 10, the most frequently used keywords in the study are “AI” (443 occurrences), “autonomous vehicles” (281 occurrences), “machine learning” (101 occurrences), “deep learning” (71 occurrences), and “autonomous driving” (72 occurrences). These keywords also rank highest in terms of total link strength, following a similar order. Notably, the most frequently used keywords also appear as prominent themes in the content analysis.

Figure 10 displays a keyword co-occurrence network that maps the conceptual structure of research in the field of AI and autonomous systems. The most prominent and central terms—“AI,” “autonomous driving,” and “explainable AI”—highlight the dominant themes and technological priorities. These core nodes are surrounded by several interconnected clusters representing subfields such as edge computing, blockchain, object detection, federated learning, and AI ethics. The strong linkage between “AI” and terms like “self-driving cars,” “robotics,” and “machine learning” suggests a deep integration of intelligent systems into mobility and transportation technologies. Meanwhile, peripheral nodes such as “AVacceptance” and “vulnerable road users” point to emerging areas of interest with a socio-technical dimension. The diversity of terms and the density of connections reflect a multidisciplinary research landscape, where technical innovation, policy considerations, and human factors converge.

3.7. Bibliographic Coupling of Documents

Bibliographic coupling refers to the situation where two independent sources cite the same third document. Based on the criterion of having received at least one citation, an analysis was conducted on 592 interconnected documents. The results revealed 13 clusters, 12,402 links, and a total link strength of 19,835.

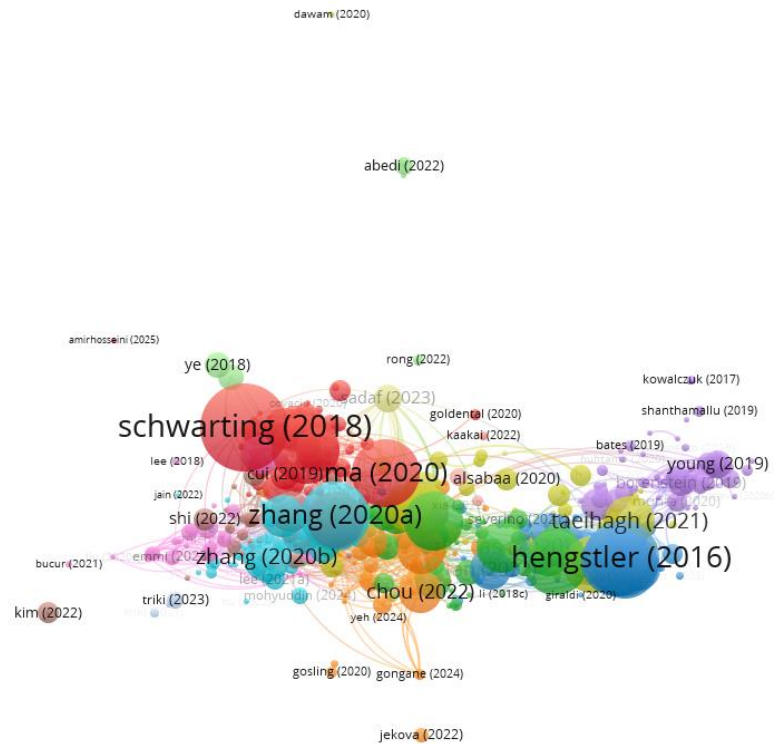


Figure 11. Bibliographic Coupling of Documents (minimum 1 citation, ranked by highest link strength).

According to Figure 11, the publications with the highest number of bibliographic couplings are Schwarting (2018a) with 559 citations, Hengstler (2016) with 410 citations, Zhang (2020a) with 347 citations, Zeng (2020) with 347 citations, and Ma (2021) with 333 citations. However, when examining total link strength, the leading publications are Atakishiyev (2024) with 42 citations, Biswas (2023) with 74 citations, Di (2021) with 136 citations, and Yeong (2025) with 3 citations. This indicates that a high number of citations does not necessarily correspond to a high link strength.

Figure 11 presents a co-citation network revealing the intellectual structure of the research domain. Larger nodes such as Schwarting (2018), Zhang (2020a, 2020b), Ma (2020), and Hengstler (2016) represent highly cited works that serve as intellectual anchors in the field. These nodes are centrally positioned and densely connected, indicating their foundational role and broad influence across multiple research clusters. The network also reveals thematically grouped clusters, each representing a stream of literature with shared theoretical or methodological orientations. For example, the cluster centered around Schwarting (2018) and Ma (2020) appears to focus on technical and algorithmic advancements in autonomous systems, while the cluster including Hengstler (2016) may emphasize ethical or socio-technical dimensions. The presence of more isolated nodes like Abedi (2022) and Dawam (2020) suggests niche or emerging topics that have not yet been deeply integrated into the main body of literature. Overall, the structure of the network highlights both the cumulative nature of knowledge production and the evolving contours of influence within the field.

3.8. Co-citation of Cited Authors

Co-citation refers to different sources that are cited together within the same publication. Based on a minimum citation threshold of 10, an analysis was conducted on 399 units. The results revealed a total of 8 clusters, 25,856 links, and a total link strength of 59,331.

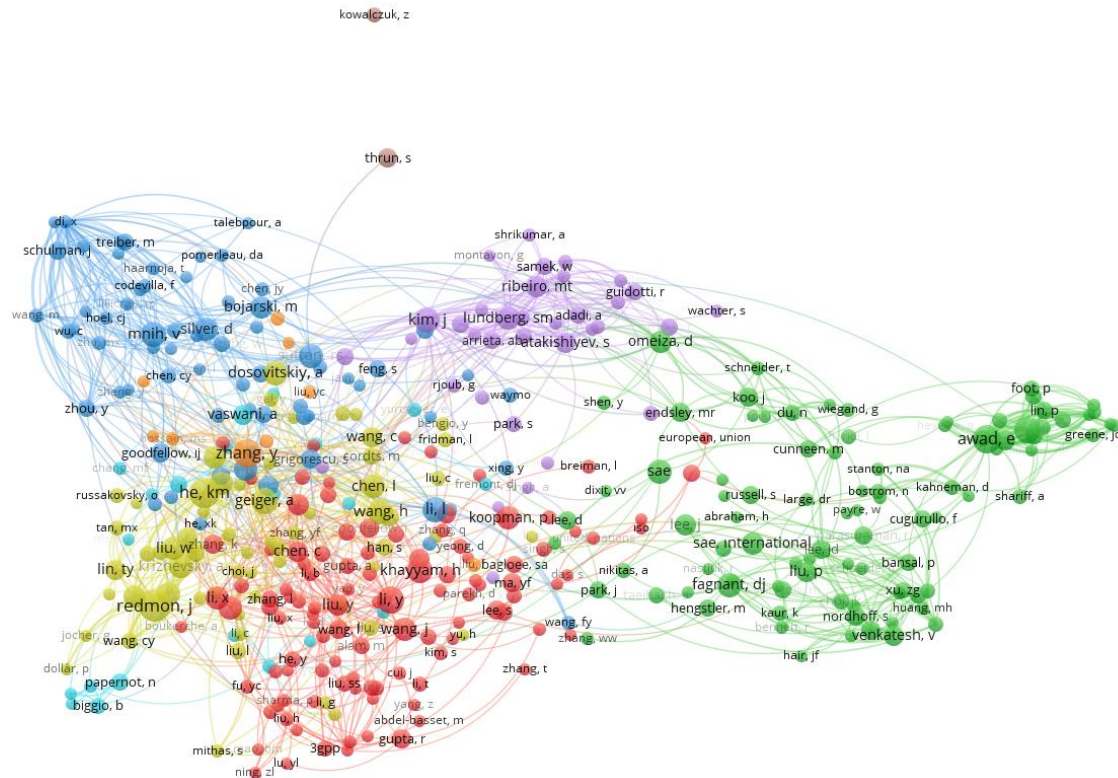


Figure 12. Co-citation of Cited Authors (minimum 10 citations, ranked by highest link strength).

According to Figure 12, the authors most frequently co-cited are J. Redmon (72), K.M. He (63), E. Awad (56), Y. Zhang (54), Y. Li (52), and A. Geiger (47). When ranked by total link strength, the leading authors are Y. Zhang (1,189), J. Kim (1,021), Y. Li (1,017), H. Wang (973), and K.M. He (957). The graph visualizes the subgroups within the research field and the interactions between these groups through color-coded clusters. Each cluster, represented by a different color, reflects a group of authors focused on specific topics or research areas in the literature. Denser connections indicate stronger citation relationships among authors, suggesting greater collaboration within particular academic domains.

Figure 12 depicts the author co-authorship network, highlighting collaborative structures within the research domain. Several prominent clusters are visible, each indicating a community of researchers with frequent collaborative ties. The blue cluster in the upper left—comprising authors such as Schulman, M., Dosovitskiy, A., Goodfellow, I., and Vaswani, A.—appears to represent a core group working on deep learning and reinforcement learning frameworks. The red and yellow clusters in the center are densely connected and include authors like Chen, Y., Liu, Y., and Zhang, W., suggesting active collaboration on topics such as autonomous vehicles and applied AI. The green cluster on the right, with contributors such as Awad, E., Venkatesh, V., and Russell, S., may reflect work on ethical, legal, and social implications of AI. The purple cluster (e.g., Ribeiro, M.T., Lundberg, S.M., Samek, W.) likely corresponds to research in explainable AI and transparency. Sparse nodes such as Thrun, S. and Kowalczyk, Z. indicate either limited co-authorship or independent contributions. Overall, the network reveals a multidisciplinary structure, where technical, social, and ethical strands of research interact but are still somewhat clustered by sub-domain.

3.9. Content Analysis

This study presents a content analysis of the most highly cited articles in the field of AI. Each article was manually coded in Excel, and a thematic analysis was conducted. A total of 25 articles were examined, and their thematic distributions, research trends, and word frequencies were analyzed.

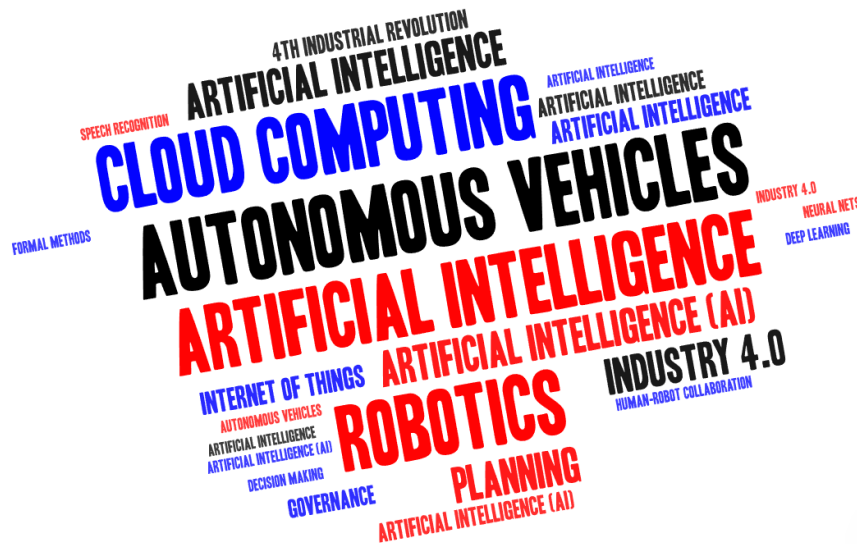


Figure 13. Word Cloud Derived from Content Analysis.

Figure 13 was generated using the key terms identified through content analysis. This word cloud clearly illustrates that autonomous vehicles are situated within a multidimensional and complex technological ecosystem. The prominence and frequent recurrence of the term “AI” in the word cloud highlight its central role in the development of autonomous vehicles, underscoring AI as the backbone of the entire system. The presence of specific AI technologies—such as deep learning, speech recognition, and formal methods—as supporting elements indicates a multilayered technological approach within the field.

The direct and bold emphasis on the concept of autonomous vehicles suggests that the studies primarily focus on the technology itself. The notable presence of cloud computing and the Internet of Things points to the critical importance of data processing, connected systems, and communication. This reveals that autonomous vehicles are not isolated systems but rather integrated technologies that continuously exchange data and operate as part of a vast digital network.

The emphasis on concepts like decision-making and planning indicates a focus on the real-time functioning of these vehicles in complex scenarios, aiming to develop intelligent systems that go beyond following pre-programmed routes and can adapt to dynamic environmental conditions.

The inclusion of robotic system integration and digital transformation within the framework of Industry 4.0 shows the industrial context of autonomous vehicles and positions them as part of the Fourth Industrial Revolution. The highlighted concept of human-robot collaboration suggests that these technologies are designed not to function entirely autonomously but rather as hybrid systems that operate in harmony with human input.

The presence of the concept of governance in the word cloud indicates that ethical and regulatory aspects are taken into account in the development of autonomous vehicles, showing that technological progress is moving in parallel with societal acceptance and legal frameworks. This comprehensive analysis makes it clear that autonomous vehicles are not merely transportation tools but represent a profound technological revolution at the core of societal, economic, and industrial transformation—approached through a multidisciplinary lens.

3.9.1 Methodology

The reviewed articles were published between 2016 and 2022 and consist of highly cited academic studies. These articles were analyzed using content analysis, and thematic categories were identified.

1. **Autonomous Vehicles and Transportation Systems:** This is the most prominently represented category. It includes studies related to planning, decision-making, and control systems for autonomous vehicles.

Schwartz, Alonso-Mora, and Rus (2018) provided a comprehensive examination of planning and decision-making processes for autonomous vehicles, emphasizing the necessity of planning methods in complex environments to ensure safe and system-compatible performance. Aradi (2022) explored deep reinforcement learning methods for motion planning and addressed the problem of hierarchical motion planning. Di and Shi (2021) investigated the transition from physics-based approaches to AI-supported driving policy learning for AV control in the era of mixed autonomy.

2. **Healthcare and Medical AI:** This category focuses on AI applications in healthcare, particularly patient safety and medical decision support systems. Hengstler, Enkel, and Duelli (2016) examined the relationship between AI and trust in the context of autonomous vehicles and medical assistance devices, highlighting the importance of societal acceptance. Esmailzadeh (2020) studied the use of AI-based tools for health from the consumer perspective, finding that technological, ethical, and regulatory concerns contribute to perceived risks.
3. **Industry 4.0 and Manufacturing Systems:** Covering smart manufacturing, robotics, and industrial automation, this category focuses on industrial applications of AI. Chatterjee et al. (2021) examined AI adoption in manufacturing firms using the TAM-TOE model and identified the moderating role of leadership support. Kim et al. (2018) reviewed smart machining processes using machine learning and defined a fully connected machine tool paradigm via cyber-physical systems.
4. **Explainable AI and Security:** This category includes research related to the transparency, safety, and explainability of AI systems. Omeiza et al. (2022) presented a comprehensive study on explanations in autonomous driving and categorized stakeholder requirements for explainability. Chou et al. (2022) explored counterfactual scenarios and causality theory for explainable AI, identifying that current algorithms often result in spurious correlations.
5. **AI Governance and Policy:** This category addresses the governance, regulation, and policy development of AI technologies. Taeiagh (2021) discussed AI governance and emphasized the need for governments to develop regulatory processes to manage socio-technical transitions.
6. **Tourism and Recreation:** This category examines applications of robotics and AI technologies in the tourism sector, particularly influenced by the COVID-19 pandemic. Zeng, Chen, and Lew (2020) investigated how COVID-19 accelerated the adoption of robotics and analyzed the shift from high-touch to high-tech experiences. Ribeiro, Gursay, and Chi (2022) explored consumer acceptance of autonomous vehicles in travel and tourism, finding that trust is the strongest determinant of performance expectations.
7. **Other Applications:** This category encompasses general AI applications and methodological approaches. Abduljabbar et al. (2019) provided an overview of AI applications in transportation, examining its use in traffic management, safety, and urban mobility.

This analysis shows that AI research peaked in 2020 and that autonomous vehicles constitute the most dominant theme. The impact of the COVID-19 pandemic has increased interest in robotics and automation. Suggestions for future research include:

- Establishing stronger connections between AI research and fields such as engineering, social sciences, and ethics.
- Conducting deeper investigations into the safety and ethical dimensions of AI systems.
- Enhancing understanding of societal acceptance processes for AI technologies.
- Improving the transparency and explainability of AI systems.

This analysis reveals that AI research is predominantly application-oriented, with particular emphasis on autonomous systems, industrial applications, and safety-related issues.

3.10. Limitations

The findings of this study should be interpreted within the framework of certain methodological limitations. First, the analysis is based solely on the Web of Science (WoS) database. The exclusion of other major data sources such as Scopus and Dimensions may have resulted in the omission of some conference papers and interdisciplinary studies, particularly in the fields of engineering and computer science (Martín-Martín et al., 2021). This limits the generalizability of the bibliometric findings obtained.

Additionally, the inclusion of only English-language publications led to the exclusion of high-quality studies published in local languages from leading research countries such as China, South Korea, and Germany. This contributes to language and coverage bias in the literature, reducing the representativeness of global scientific output (Mongeon & Paul-Hus, 2016).

Another significant limitation is the keyword-based search strategy used in the study. The focus on the terms "autonomous vehicles" and "AI" has led to the exclusion of certain subfields that are directly related to autonomous systems, such as V2X communication, ethical algorithms, and edge computing. This has resulted in the underrepresentation of some critical concepts in the keyword co-occurrence analysis (Figure 10) (Gusenbauer & Haddaway, 2020).

A further temporal limitation is that, as of the data collection date (July 9, 2025), the citation cycles for publications from the year 2025 have not yet been completed. Consequently, the impact of these recent publications may appear lower than it actually is, particularly in Figure 6 and Table 1, which present annual citation counts (Glanzel, 2003).

Lastly, the content analysis was limited to the 25 most highly cited articles. This may have led to the exclusion of low-citation but pioneering works, resulting in potential bias in the representation of thematic trends (Zupic & Čater, 2014). Considering these limitations, future studies are recommended to adopt broader data sources, include multilingual publications, and implement more inclusive analysis strategies.

4. Conclusion and Discussion

This study provides a comprehensive overview of the scientific literature emerging at the intersection of autonomous vehicles and AI from 2015 to 2025 through both bibliometric and thematic analyses. The findings indicate a marked increase in publication volume, particularly after 2019; the number of annual publications reached 195 in 2024, underscoring the rapid development of the field (Figure 2). This growth reflects AI's central role in autonomous technologies, supported by a 1,950% increase in citations between 2020 and 2024 (Figure 6). During this period, seminal works such as Schwarting et al. (2018) and Hengstler et al. (2016) laid the theoretical and practical foundations of the field through high citation counts (Table 1).

Author collaboration analyses (Figure 7) show that research networks are largely concentrated in the USA, China, and the UK—countries that also lead in both publication and citation volumes (Figure 4). Keyword (Figure 10) and content analyses (Figure 13) reveal that the literature primarily focuses on technical areas such as planning algorithms, deep learning methods, and Industry 4.0 integration. However, structural imbalances in interdisciplinary coverage have also been observed. The findings show that approximately 78% of the publications stem from engineering and computer science disciplines, while social dimensions such as ethics, governance, and public acceptance are represented in less than 10% of the literature (Section 4.1). This imbalance may pose a risk to the harmonious integration of AI into society (Taeihagh, 2021).

The post-pandemic rise in the adoption of robotics and autonomous systems (Zeng et al., 2020) underscores the strategic importance of these technologies during crises, but it has also introduced challenges related to trust and acceptance in human-machine interaction. Enhancing transparency in decision-making processes has become critical to achieving public acceptance (Chou et al., 2022).

Additionally, the emphasis on technologies like IoT and cloud computing in the content analysis (Figure 13) signals a need for prioritizing cybersecurity and data privacy in future research. This need extends to the entire connected vehicle ecosystem, which is increasingly characterized by a fusion of autonomy and electrification. In this context, secure system architectures for vehicle-to-grid (V2G) communication and user authentication, as explored in studies like Aydın (2021) for electric vehicles, will become increasingly critical and an integral part of the trusted autonomous ecosystem.

While most academic studies on autonomous vehicles and AI focus on technical innovations, the representation of the social sciences remains limited (10%). This leads to significant gaps in crucial areas such as societal acceptance, ethical regulations, and user trust. To address this interdisciplinary imbalance, projects like the European Union's AI4People initiative—which aims to foster constructive dialogue between technology and ethics—should be expanded (Floridi et al., 2018). Furthermore, standards such as IEEE P7000 should be localized through collaborative efforts between engineering and social science experts, and the sociopsychological aspects of human-AI interaction should be assessed using quantitative methods (IEEE, 2023). Such interdisciplinary efforts will ensure that technological progress is not only technically sound but also socially legitimate.

From the perspective of policymakers and industry leaders, developing a multi-layered regulatory framework is a critical need. At the global level, transparency requirements for AI decision-making algorithms should be mandated based on UNECE WP.29 regulations (Taeihagh, 2021; UNECE WP.29, 2024). At the national level, the creation of ethical committees such as algorithmic audit offices to determine responsibility in AV accidents is recommended (Winfield & Marina, 2018). On the industry side, the development of trust index simulators—including social acceptance tests to measure user trust—should be promoted, with examples like Waymo's "Trust Indicator Toolkit." Finally, the establishment of "Human-AI Partnership Labs," where social scientists and data scientists work together, can strengthen public-private sector synergy and promote more inclusive and sustainable adoption of the technology (Shneiderman, 2020).

AI research in AV is growing rapidly, yet ethical and societal aspects remain underexplored. This reveals a significant gap in the societal integration of AI. Despite methodological limitations such as reliance solely on the WoS database and English-language publications (see Section 5), this study systematically maps the current state of the field and offers several recommendations for future research. Methodologically, the inclusion of additional databases such as Scopus and IEEE, as well as the use of semantic analysis tools, is advised. At the thematic level, focusing on areas such as V2X communication, simulation-based safety testing, and comparative analyses of global regulatory standards will help the literature evolve in a more balanced and inclusive manner.

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Conflict of Interest Statement, if any

There is no conflict of interest with any institution or person within the scope of the study.

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