DRIVING SAFETY AND COMFORT: A BIBLIOMETRIC ANALYSIS OF THE ROLE OF AUTOMOBILE HEADLIGHTS

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Abstract: This study analyzes research trends in vehicle headlights, focusing on publications related to driving safety and comfort. The research aims to reveal the developments in headlight technologies, the effects of lighting performance on driving safety and comfort, the use of headlights in different road and weather conditions, and the general trends in scientific studies on these subjects. A combined quantitative and visual analysis approach is used to comprehensively understand the intellectual accumulation, citation patterns, influential researchers, and the evolution of research themes over time. The analysis covers 953 publications, from which a sample of 241 was selected using the keywords "vehicle or car and headlight or headlamp," and reveals a recent increase in research activities, especially in 2021-2024, reflecting the automotive industry's emphasis on advanced driver assistance systems and innovative lighting technologies. Multi-authored publications were found to have higher citation counts, demonstrating the value of collaboration. Temporal distribution analysis shows an increasing research interest in vehicle headlights. The findings highlight key influencers and collaboration networks within the field, emphasizing the importance of international partnerships in addressing common challenges related to road safety and driving innovation. This study provides insights into emerging research trends and potential gaps, guiding future research directions in the pursuit of safer and more comfortable driving experiences.

Keywords: Automobile Headlights, Driving safety, Driving comfort, Bibliometric analysis.

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1. INTRODUCTION

The safety of drivers during nighttime travel is a pressing concern that merits significant attention, particularly as night driving is associated with higher accident rates compared to daytime conditions. One crucial aspect of this safety challenge is nighttime sight distance, which remains inadequately addressed in current highway design guidelines. Traditional two-dimensional models used to assess sight distance often fail to account for the complexity of various roadway alignments and roadside obstructions, leading to potential misestimations of visibility (César et al., 2016). Furthermore, innovations in headlamp technology have the

potential to significantly improve driver safety. For instance, a Smart Headlamp system can reduce instances of temporary blindness caused by oncoming headlights, a common occurrence during night driving (Fechtner et al., 2019; Toney & Bhargava, 2021). By exploring both design and technological advancements in headlamps, this investigation aims to enhance our understanding of factors influencing driver safety at night and propose necessary improvements for future vehicle technology.

1.1. Importance of headlamp functionality in ensuring driver safety

The functionality of headlamps is critical for ensuring driver safety, particularly in low-light and adverse weather conditions. Effective illumination not only enhances visibility for the driver but also serves to alert other road users to the vehicle's presence. Poorly functioning headlamps can obscure road hazards, increase the likelihood of collisions, and significantly compromise the overall safety of nighttime driving. Moreover, advanced technologies, such as those simulated through digital twins, can be utilized to optimize headlamp performance by accurately replicating light effects and assessing various driving scenarios (Dawid et al., 2024). Furthermore, the increasing complexity of modern vehicles necessitates a thorough understanding of headlamp functionality in the context of vehicle cybersecurity, as any vulnerabilities could lead to malfunctions that endanger driver safety (Merola et al., 2024). Thus, a rigorous approach to headlamp functionality is essential for maintaining safe driving practices and reducing accident rates.

1.2. Types of headlamps

An understanding of the different types of headlamps is crucial for enhancing driver safety, particularly during nighttime travel. Headlamps can be categorized primarily into halogen, LED, and HID (High-Intensity Discharge) types. Halogen headlamps are the most traditional and provide adequate illumination; However, they consume more energy and have a shorter lifespan compared to their modern counterparts. LED headlamps, on the other hand, offer increased energy efficiency and a longer operational life due to their lower heat production and durability. This is especially pertinent considering that nearly 50 percent of fatal motor vehicle crashes occur at night, often attributed to reduced visibility and reliance on visual cues, This fact emphasizes the critical role of effective lighting in driver safety (Franz, 2009). Additionally, advancements such as on-road projections can provide visual communication between vehicles and pedestrians, thereby enhancing situational awareness and reducing distraction for drivers (Glück et al., 2021).

1.3. Comparison of halogen, LED, and HID headlamps in terms of visibility and safety

The ongoing evolution of automotive lighting technology, particularly halogen, LED, and HID headlamps, presents significant implications for visibility and safety on the road. Halogen headlamps have traditionally been favored for their affordability and adequate visibility but fall short in efficiency and luminosity compared to emerging alternatives. In contrast, LED headlamps offer improved illumination and a longer lifespan, yet their intense brightness can lead to increased glare for oncoming drivers, especially older adults who are more susceptible to visual discomfort and decreased performance under glare conditions, as highlighted by research demonstrating the adverse effects of HID headlights on visual acuity across different age groups (Friedland, 2012). Furthermore, the broad spectrum of light emitted by these advanced headlamp types also risks ecological disruption, drawing attention to the need for balanced designs that mitigate glare while prioritizing safety (Gaston et al.). As vehicle

manufacturers refine these technologies, the integration of glare-mitigation strategies is essential to enhance driver safety.

1.4. Maintenance and regulations

Effective maintenance and adherence to regulations are crucial for ensuring driver safety, particularly regarding vehicle headlamps. Properly functioning headlamps significantly enhance visibility, especially during nighttime driving when the majority of fatal accidents occur due to reduced visual cues on the road (Franz, 2009). Regulatory frameworks, such as the new MUTCD standards on traffic sign retro reflectivity, aim to address these safety concerns by improving nighttime visibility for drivers (Franz, 2009). Furthermore, advancements in automotive design emphasize the integration of sustainability with functionality, prompting manufacturers to adopt life cycle thinking approaches that prioritize both performance and environmental impact. This dual focus not only addresses the immediate safety needs of drivers but also promotes long-term sustainability within the automotive sector. By complying with established maintenance protocols and regulations, drivers can ensure their headlamps operate optimally, thereby enhancing overall road safety and contributing to a more responsible driving culture.

1.5. Overview of headlamp maintenance practices and legal requirements for vehicle safety

In the context of vehicle safety, headlamp maintenance practices are essential for ensuring both driver visibility and compliance with legal standards. Regular inspections of headlamps are necessary to guarantee their functionality, as malfunctioning lights can severely impair vision, especially during nighttime driving, leading to potentially hazardous situations on the road. Moreover, the legal requirements mandate that vehicle headlamps must operate within specified brightness standards to enhance road guidance for drivers, as inadequate lighting can contribute to accidents due to poor visibility (Vrábel et al., 2023). Additionally, the automotive industry's commitment to sustainable practices, as outlined in various initiatives, underscores the importance of integrating eco-friendly materials and designs in headlamp production, thereby aligning with broader environmental goals (Brumbelow, 2022). Consequently, adherence to these maintenance practices and legal specifications not only promotes driver safety but also supports the ongoing transition towards more sustainable vehicle technologies.

In conclusion, the effectiveness of vehicle headlamps plays a pivotal role in ensuring driver safety, particularly during nighttime driving conditions. As the analysis reveals, many accidents stem from human errors exacerbated by inadequate lighting or obstructions in visibility caused by oncoming traffic headlights. The integration of advanced technologies, such as Smart Headlamp systems, could significantly reduce the risk of high beam blindness, allowing drivers to make safer overtaking decisions (Toney & Shety, 2021). Moreover, understanding the challenges faced by different vehicle types, particularly those with higher eye levels such as trucks, underscores the necessity for specific adaptations in headlamp design (Sivak et al., 1993). By prioritizing these technological enhancements and tailoring safety features to accommodate varied driving scenarios, we can enhance road safety and mitigate the risks associated with nighttime driving. The collective responsibility of manufacturers, policymakers, and drivers is essential for fostering a safer driving environment.

1.6. Summary of the impact of headlamp technology and maintenance on overall driver safety

The efficacy of headlamp technology and diligent maintenance practices significantly influences overall driver safety, particularly during nighttime driving conditions. Approximately 50 percent of fatal motor vehicle crashes in the United States occur at night, highlighting the critical need for effective illumination systems that enhance visibility and inform drivers of their surroundings (Franz, 2009). Advanced headlamp technologies, such as adaptive lighting and LED systems, provide drivers with improved visibility by better illuminating road conditions and potential hazards. Moreover, the regular maintenance of headlamps, including the replacement of burnt-out bulbs and the cleaning of lenses, can prevent debilitating visibility issues that could contribute to accidents. As the automotive industry moves toward sustainable practices, integrating environmentally friendly materials and efficient technologies into headlamp design reflects a broader commitment to driver safety and environmental responsibility (Maltese, 2019). Ultimately, the marriage of advanced headlamp technology and responsible maintenance is paramount for enhancing driver safety on the roads.

Road safety is a critical concern in the field of transportation, with factors such as vehicle design, infrastructure, and driver behavior playing a key role in determining the safety and comfort of road users. Among these factors, the role of vehicle headlights has received significant attention from researchers, as they are essential for visibility and safety, particularly in low-light conditions (Brumbelow, 2022); Vrábel et al., 2023).

Existing literature has explored various aspects of headlight technology and its impact on driving safety and comfort. These studies have highlighted the importance of real-time safety metrics for automated driving systems, the need to accommodate the human element in transportation systems, and the potential of intelligent headlight control systems to enhance visibility and reduce accidents.

The research landscape in this field is diverse, with studies examining topics ranging from the development of automatic headlight leveling systems (Fechtner et al., 2019) to the detection of oncoming vehicles for intelligent headlight control (López et al., 2008). However, a comprehensive bibliometric analysis of the research trends, key contributors, and influential publications in this domain is lacking.

This bibliometric study aims to provide a holistic understanding of the research landscape surrounding the role of headlights in driving safety and comfort. The analysis will identify the most influential publications, the leading researchers, and the emerging trends in this field, offering valuable insights for researchers, policymakers, and industry stakeholders.

1.7. Bibliometric analysis

Bibliometric analysis is a research method employing statistical and mathematical tools to examine large bodies of scholarly literature. It quantifies aspects of publications, such as authorship, citations, keywords, and publication venues, to reveal patterns and trends within a specific field of study (Yan & Zhiping, 2023). This quantitative approach allows researchers to map the intellectual landscape of a topic, identify influential authors and publications, track the evolution of research themes, and gain insights into the overall structure and dynamics of academic discourse (Whitney et al., 2019). By analyzing citation patterns, bibliometric analysis can reveal the impact of specific works and authors, as highly cited articles are generally considered to be influential contributions to the field (Xie et al., 2020). Furthermore, bibliometric analysis can uncover emerging research areas and highlight potential gaps in

existing knowledge (Cipollina et al., 2021). This methodology offers a valuable means of understanding the historical development, current state, and potential future directions of a given research area.

2. MATERIAL AND METHOD

A combination of citation analysis, co-authorship patterns, and keyword co-occurrence was utilized to identify the most influential publications, key research topics, and emerging trends in the field of headlights and driving safety.

An important database, such as Web of Science, was searched using keywords related to "headlights", "driving safety", and "driving comfort". The citation patterns of the retrieved publications were analyzed to identify the most influential works in the field. Additionally, the co-authorship networks were examined to uncover the collaborative dynamics among researchers, as well as the keyword co-occurrence to map the thematic structure of the research.

The research was conducted on February 12, 2025, selecting all years and all Web of Science indices in the filtering area. As a result of this search, 241 articles were found and these 241 articles were selected as a sample (http://apps.webofknowledge.com, Access Date: 12.02.2025).

The bibliometric analysis method was adopted in the study, and the VOSviewer program was used to examine the publications. Publication year, most frequently used keywords, country with the most publications, researcher with the most publications, researcher with the most co-authorships, country with the most citations, and researcher with the most citations are provided for the 241 publications examined. In addition, visual analysis was performed by creating network maps and the obtained findings were discussed.

2.1. Data Collection and Search Strategy

The publications for this bibliometric analysis were collected from the Web of Science (WOS) Core Collection database, provided by Clarivate Analytics. To clearly define the scope and thematic focus of the study, a detailed search strategy was established, encompassing both general Topic terms and specific Citation Topics Micro.

The primary search query applied was as follows:
"(vehicle OR car) AND (headlight OR headlamp) (Topic) AND (4.183.669 Road Safety OR 4.169.2376 Light Pollution OR 4.17.128 Deep Learning OR 4.183.486 Traffic Flow OR 1.36.813 Myopia OR 1.36.212 Retina OR 7.300.908 Asphalt Mixture OR 1.5.1090 Fear Conditioning OR 1.247.461 Migraine OR 1.129.98 Low Back Pain OR 6.73.1369 Evolutionary Psychology OR 4.284.2778 Artificial Intelligence OR 4.29.104 Adaptive Control OR 4.48.322 Semantic Web) (Citation Topics Micro)"

To ensure the academic credibility and relevance of the retrieved results, the publications were further filtered by applying the following WOS index restrictions:

- SCI-EXPANDED (Science Citation Index Expanded)
- SSCI (Social Sciences Citation Index)
- A&HCI (Arts & Humanities Citation Index)
- ESCI (Emerging Sources Citation Index)

- CPCI-S (Conference Proceedings Citation Index – Science)
- CPCI-SSH (Conference Proceedings Citation Index – Social Science & Humanities)
- BKCI-S (Book Citation Index – Science)
- BKCI-SSH (Book Citation Index – Social Science & Humanities)

This comprehensive filtering strategy was designed to include interdisciplinary publications closely related to the research area, such as those from engineering, computer science, traffic psychology, and visual sciences. The total number of publications retrieved through this precise strategy formed the basis of our analysis.

2.2. VOSviewer

VOSviewer is a software tool for constructing and visualizing bibliometric maps. These maps represent the relationships between different academic entities, such as authors, publications, or keywords. By analyzing co-occurrence, co-citation, or bibliographic coupling, VOSviewer creates network visualizations that reveal clusters of related items, highlighting key themes, influential works, and collaborative patterns within a research area (Van Eck & Waltman, 2017).

3. RESULTS

In the visualization provided by VOSviewer, each circle represents an item selected according to filtering criteria determined by the researcher (Van Eck & Waltman, 2009). This item could be a country, author, document, term, or similar data point. The size of the circle indicates the frequency of occurrence of the corresponding item; the largest circle represents the most frequently occurring item. Items are color-coded and clustered into groups according to their occurrence scores (Bukar et al., 2023). While each item can only belong to one cluster, it's also possible for some items not to belong to any cluster (Girvan & Newman, 2002). The lines between the items represent the strength of the connections. Thin lines indicate weaker connections, while thicker lines represent stronger connections (VOSviewer - Visualizing Scientific Landscapes, 2023). This visualization method offers a useful tool for understanding the complex structure and relationships within scientific research (Van Eck & Waltman, 2009; VOSviewer - Visualizing Scientific Landscapes, 2023). VOSviewer is a software frequently used, especially in bibliometric analyses, assisting researchers in mapping research areas, identifying trends, and highlighting key actors (Bukar et al., 2023; Husaeni & Nandiyanto, 2021). This type of analysis is particularly valuable in rapidly evolving fields, such as digital learning, for evaluating research performance and setting directions for future studies (Husaeni & Nandiyanto, 2021).

3.1 Keyword analysis

Figure 1 illustrates the keywords used in publications on "driving safety and comfort" and "car headlights" indexed in Web of Science. From a total of 2640 keywords, 68 were selected based on a minimum frequency of five occurrences. The most frequent keyword is "vehicle detection" (35 occurrences), followed by "LED" (26 occurrences). Other prominent keywords include "headlamp," "headlight," "glare," "headlights," "visible light communication," "automotive lighting," and "road safety." Notably, variations of "headlight" (headlamp, headlights, car headlights, vehicle headlights, headlamps, vehicle headlamps) collectively appear 89 times.

This visualization, generated using VOSviewer, maps the most frequent keywords in publications on these topics. The graphic visualizes current research trends and focal points

within the field. Keyword size represents relevance and frequency, with larger words indicating greater importance. Keyword proximity reflects conceptual relationships; closer words suggest concepts often discussed together. The analysis reveals that "driving safety and comfort" and "car headlights" are prominent themes, representing key areas of research focus.
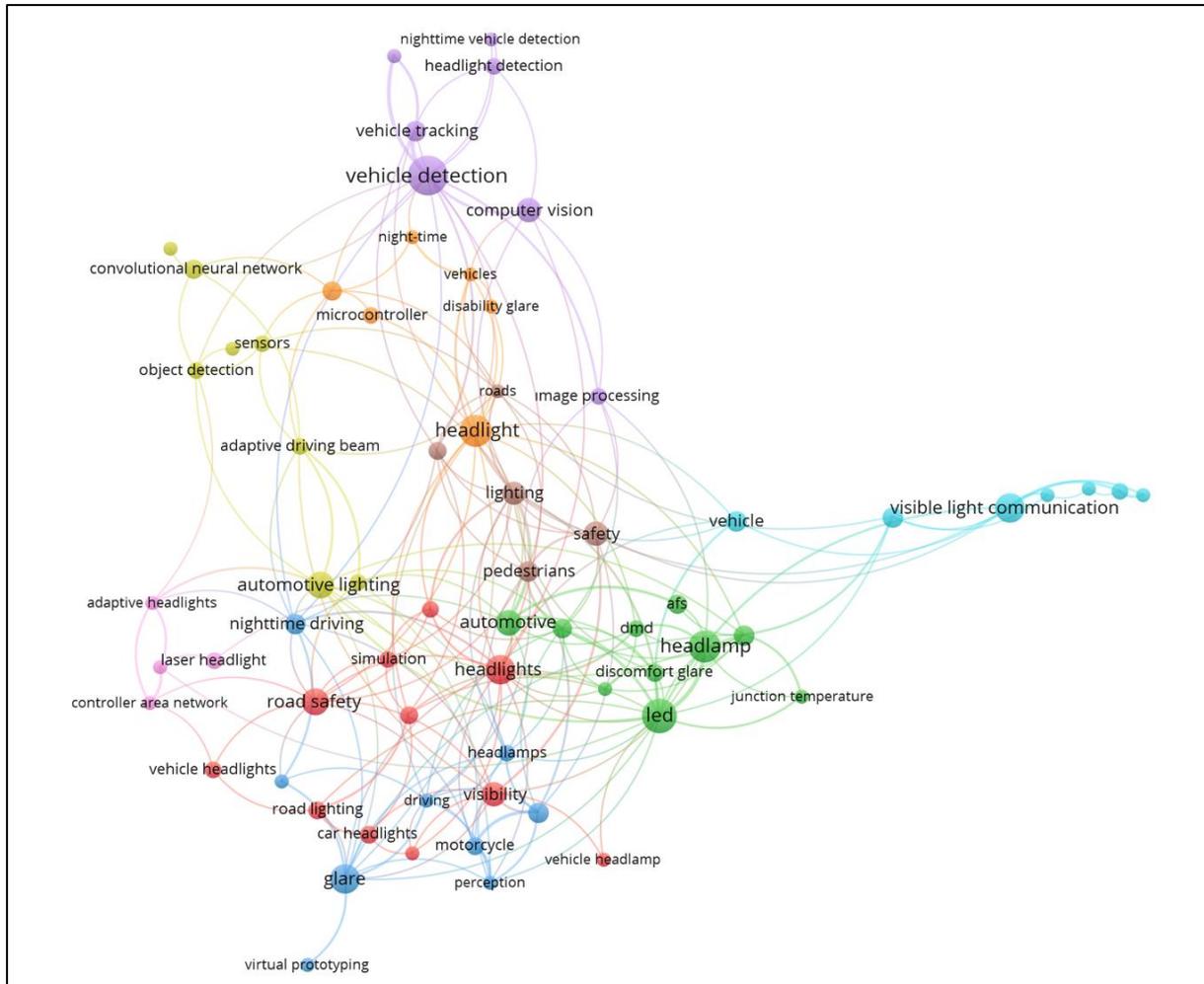

Figure 1. Keyword analysis

This graph in Figure 3.1 reveals the strong relationships between research topics in the field of vehicle lighting technology. The red and orange clusters in the center show how closely headlights and lighting systems are connected to topics like road safety and adaptive driving. Furthermore, the purple cluster on the top left shows that topics such as vehicle detection, computer vision, and artificial neural networks play a critical role in the development of lighting systems, especially for nighttime driving. The green and blue clusters on the right focus on the more technical aspects of LED technology, namely thermal topics like junction temperature and innovative applications like visible light communication.

3.2. Most co-authorship analysis

Figure 2 presents the researchers with the most co-authorships. A total of 2995 researchers were identified in the publications analyzed. Of these researchers, 21, who had at least 1 publication and at least 5 citations, were considered. The color of the area containing the researchers' names in the figure varies according to the number of co-authorships. Blue indicates a small number of co-authorships, while yellow indicates a larger number of co-authorships. Examining the

figure, it can be seen that the researcher with the most co-authorships is Chi, Nan(38). This researcher is followed by Lin, Shih-Kang, Sun, Ching-Cherng, Wu, Chi-Shou, Yang, Tsung-Hsun(34), and Yu, Yeh-Wei (29), in order.
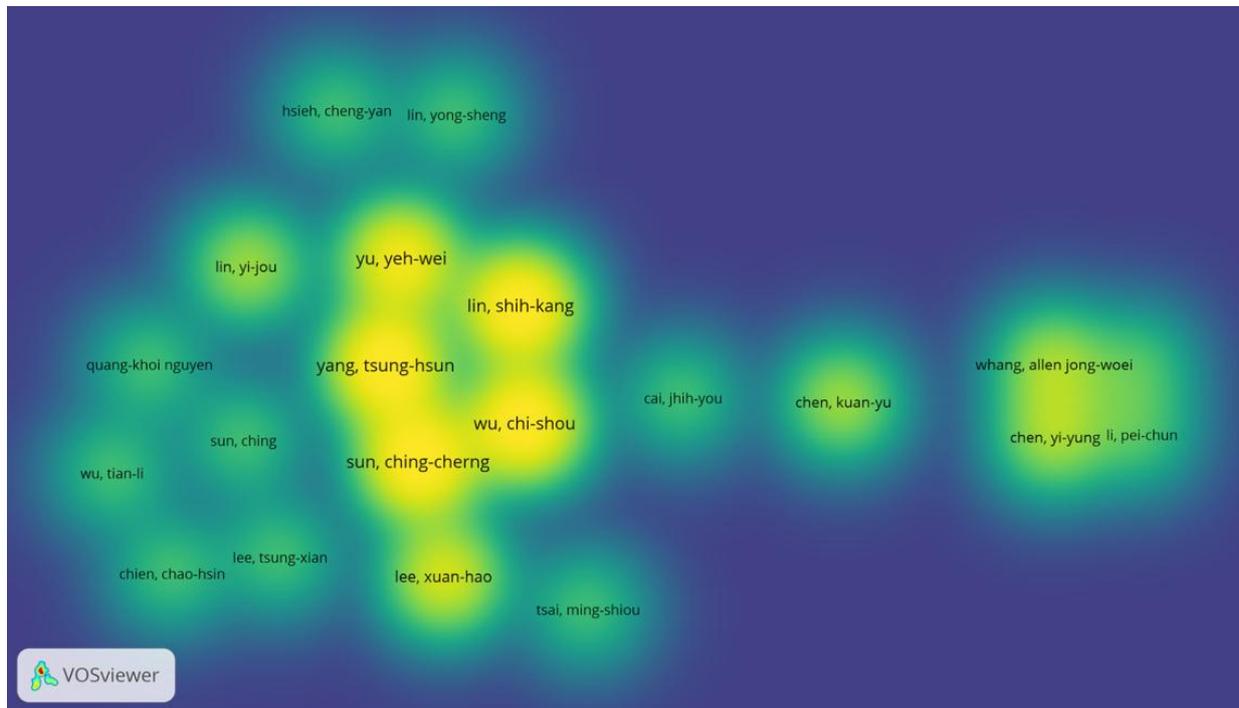

Figure 2. Researchers with the most co-authorships

The density visualization in Figure 2 effectively maps the researchers and groups with the strongest co-authorship relationships within a specific scientific or academic field. The color intensity, transitioning from yellow to green and purple, indicates the frequency and strength of collaboration between an author and others in the network:

The Central and Most Dense Cluster (Yellow Area): The brightest and most central region of the map represents the tightest and most productive co-authorship network, formed by authors such as Yang, Tsung-hsun, Lin, Shin-kang, Sun, Ching-cherng, and Wu, Chi-shou. These authors have collectively produced the most publications on core research topics in the field, making them the core actors of the ecosystem.

Peripheral and External Groups (Green and Purple Areas): The decrease in density towards the map's edges indicates authors who collaborate less frequently or within smaller, more isolated groups. For example, the cluster led by Whang, Allen Jong-woei is separated geographically or thematically from the central group but maintains strong internal collaboration. Such groups are typically peripheral actors with weaker ties to the main network or focus on different subtopics.

Collaboration Strategy Insight: This map highlights that the flow of information and interaction within the field is largely channeled through these central clusters, establishing these core authors as the key influential figures who drive the research agenda.

3.3 Analysis of countries with the most publications.

Figure 3 presents information on the global distribution of research related to car headlights, driving safety, and comfort. This figure highlights not only the leading countries in this field but also the collaborative networks driving innovation in headlight technologies.

Countries are ranked according to the number of published documents, citations received, and total link strength. The United States leads in the number of documents and citations, indicating a substantial research presence. China follows with 160 documents and 1173 citations, demonstrating its growing contribution to the field. Germany and Taiwan also emerge as significant contributors. The presence of countries like India, South

Korea, and Japan further emphasizes the global nature of this research area. It is important to note that "total link strength" is likely a composite measure, possibly derived from co-authorship or citation patterns, reflecting interconnectedness among research activities across countries.

These findings demonstrate the global nature of research on car headlights and their connection to driving safety and comfort. The prominence of certain countries underscores their leadership in this area, while the collaborative links highlight the importance of international partnerships in driving innovation and addressing shared challenges related to road safety. Further investigation into the specific research areas within each country and the nature of collaborative projects could yield more nuanced insights.
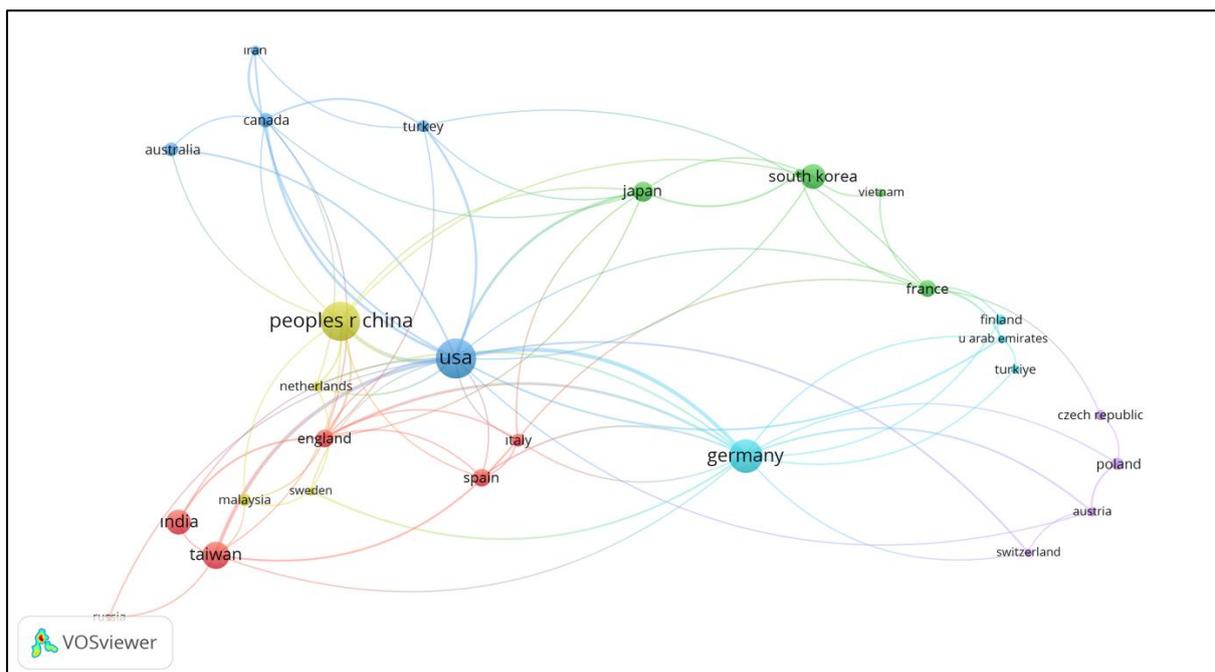

Figure 3. Analysis of countries with the most publications.

Shown in Figure 3 the network map clearly demonstrates that the USA and Germany stand out as the largest nodes in the research field, positioning these two countries as the central actors of the global collaboration network. The USA, in particular, forms the most intensive collaboration hub in the network due to its robust connections with both China (Peoples R China) and various European and Asian countries.

Despite having a large research output, China's collaboration structures are often positioned closer to the USA; whereas Asian countries like Japan and South Korea form a distinct

collaboration cluster, establishing strong ties amongst themselves and with Germany. Finally, countries such as India and Taiwan in the bottom left of the map form more localized collaboration clusters, primarily limited to their own regions and specific European partners like the UK/England and Spain.

3.4. Analysis of author citation networks and influence

The analysis of author citation networks offers valuable insights into the structure and dynamics of the research landscape pertaining to car headlights, driving safety, and comfort. This examination reveals key influencers, collaborative patterns, and the overall knowledge flow within the field.

Figure 4 presents the most cited researchers, considering 139 researchers with at least two publications and one citation. The most cited researcher is Andreas Herrmann (330). Following Herrmann, in descending order of citation count, are Yuxiang Sun, Bing-fei Wu (253), Ming Liu (252), Murat Uysal (252), Jan R. Landwehr (248), Yen-lin Chen (239), Hao-yu Huang (178), and Yee Mun Lee (174). The figure indicates that the top-performing researchers are primarily affiliated with universities in Germany, China, Taiwan, and Turkey.
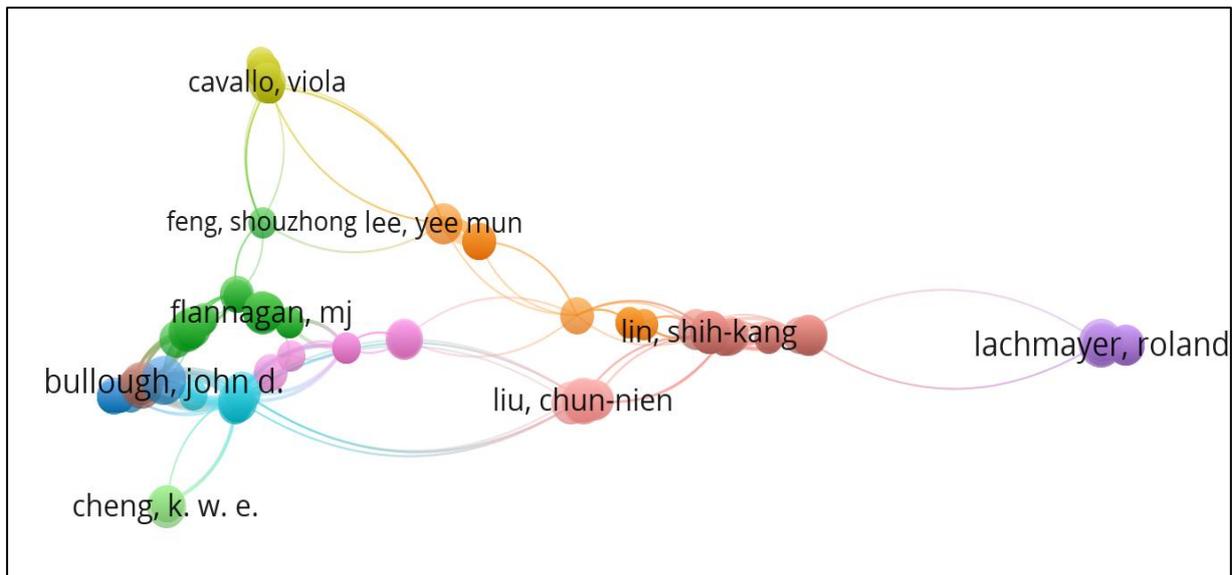

Figure 4. Analysis of Author Citation Networks and Influence

The visualization of these citation connections as a network graph further illuminates the relationships between researchers. Authors are represented as nodes, with the connections between them representing citations. The density of these connections, often depicted by the thickness of the connecting lines, reflects the frequency of citation between authors. This graphical representation can reveal clusters of interconnected researchers, potentially signifying collaborative groups or areas of focused research activity. Such collaborative networks can be instrumental in advancing specific technologies like adaptive driving beams (Fechtner et al., 2019) or addressing critical issues such as glare and driver perception. (Mehri et al., 2017; Weaver & DeLucia, 2022) Further analysis of these clusters might uncover specialized research domains within the broader field.

This combined quantitative and visual analysis provides a comprehensive understanding of the intellectual landscape. By examining citation patterns, we gain insights into not only the most influential researchers but also the potential for future collaboration and the evolution of research themes over time. The directionality of citations, from older to newer works, can further elucidate the trajectory of research within this domain. Furthermore, this approach can help identify emerging research trends and potential gaps in the existing literature.

3.5 Most cited publications

Figure 5 shows the most cited publications. Out of a total of 953 publications analyzed, 664 publications with at least one citation were found, and 231 of these publications were taken into consideration. Examining the figure, it can be seen that the most cited publication is that of Lin(2009, 325 citation). This publication is followed by Quddus(2002, 278 citation), Sun(2019, 250 citation), Landwehr(2011, 212 citation), O'Malley(2010, 164 citiation), Chen(2011, 142 citation), Zhou(2007, 140 citation), Uysal(2015, 132 citation), Unzueta(2012, 119 citation), and Jermakian(2011, 113 citation), in order.
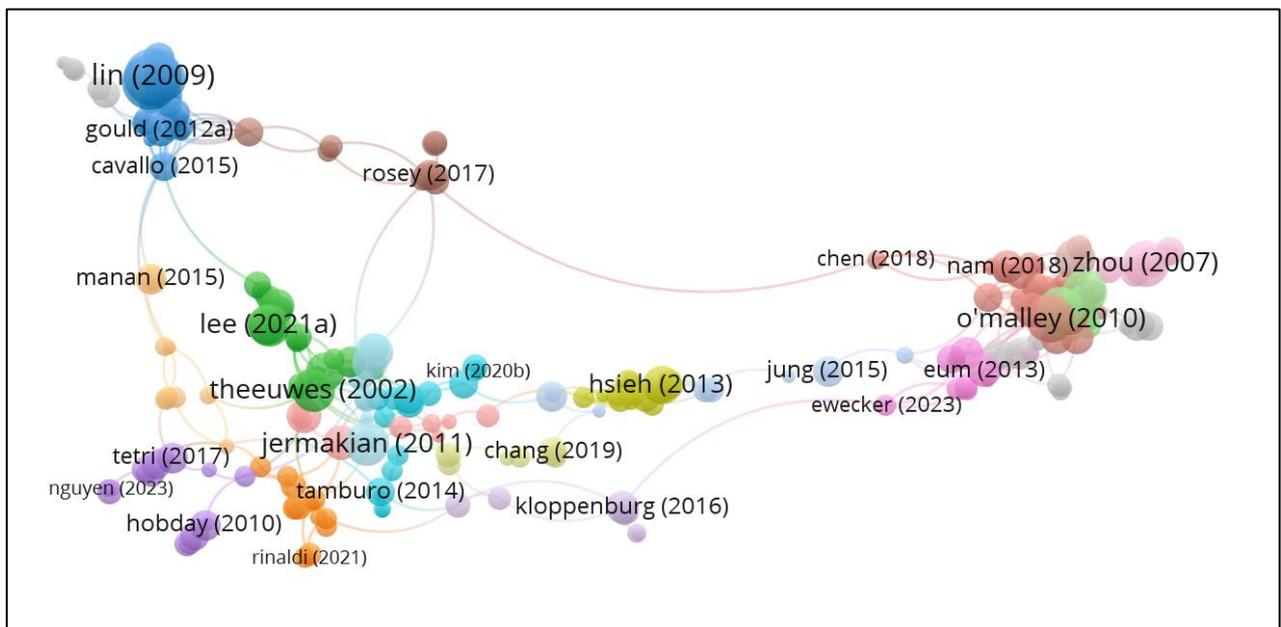

Figure 5 Most cited publications

There are important indicators that show the quality and impact of publications. The citation counts of publications demonstrate their level of contribution and effectiveness in the field. It is known that publications with high citation counts are more prestigious and of higher quality (González-Brignardello et al., 2023) (Redner, 1998).

In addition, the multi-authorship of publications is also a remarkable finding. It has been observed that multi-authored publications have higher citation counts (Kosmulski, 2017; Redner, 1998).

It is observed that studies published especially in 2018-2019 have become quite popular. This is due to the acceleration of scientific publishing and the increase in studies conducted in this field, which explains the increase in citation counts during this period."

3.6 Distribution of publications over the years

Figure 6 shows the distribution of publications related to vehicle headlights, driving safety, and comfort over the years. This temporal analysis provides important insights into research trends and the increase in interest in this area over time. A noteworthy observation is the recent increase in the number of publications. The years 2021, 2022, and 2024 account for a significant portion of the total publications. This surge may reflect an increasing focus on advanced driver assistance systems, including smart headlight technologies such as adaptive driving beams and the integration of sensor-based equipment. The development and application of LED and other innovative lighting systems also contribute to this trend.
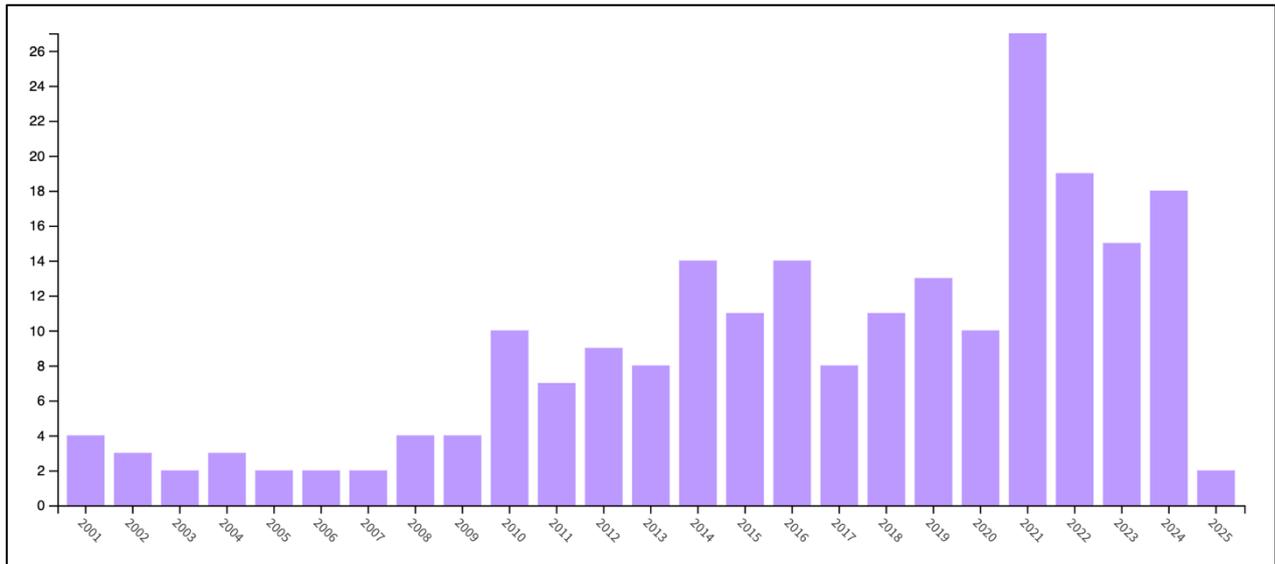

Figure 6 Distribution of publications over the years

Although there has been a noticeable concentration of publications in recent years, the data also reveals steady research activity dating back to the early 2000s. While the number of publications in the years between 2001 and 2019 is generally lower compared to the recent increase, these represent foundational research that paved the way for current advancements. Three records with missing publication year data were excluded from the analysis, as they represent a small fraction of the total dataset.

This temporal distribution analysis demonstrates a growing research interest in vehicle headlights, particularly focusing on their roles in enhancing driving safety and comfort. The increased number of publications in recent years aligns with the automotive industry's focus on innovative lighting technologies and the integration of smart functions into vehicles. This trend indicates that research in this area will continue to expand, driven by ongoing technological developments and the pursuit of safer and more comfortable driving experiences.

4. DISCUSSION AND CONCLUSIONS

The analysis of research trends in vehicle headlights, driving safety, and comfort reveals several key insights. The increasing number of publications in recent years, particularly in 2021, 2022, and 2024, indicates a growing focus on this area. This surge likely reflects the automotive industry's emphasis on advanced driver assistance systems and innovative lighting technologies, such as adaptive driving beams and LED systems.

The prominence of certain countries, such as Germany, China, Taiwan and Turkey, in the research landscape underscores their leadership in this field [Figures 3, 4]. Collaborative links between researchers across different countries highlight the importance of international partnerships in driving innovation and addressing shared challenges related to road safety.

Furthermore, the analysis of author citation networks identifies key influencers, such as Andreas Herrmann, and collaborative patterns within the field [Figure 4]. These

networks play a crucial role in advancing specific technologies and addressing critical issues like glare and driver perception.

The analysis of publications also reveals that multi-authored publications have higher citation counts, demonstrating the value of collaboration and diverse perspectives in research. Moreover, studies published in 2018-2019 have gained considerable popularity, likely due to the acceleration of scientific publishing and increased research activity in this domain.

While recent years have witnessed a concentration of publications, steady research activity has been ongoing since the early 2000s. These earlier studies provide the foundational research that paved the way for current advancements.

In conclusion, this analysis demonstrates a growing research interest in vehicle headlights and their impact on driving safety and comfort. The increasing number of publications, the prominence of certain countries and researchers, and the collaborative networks within the field all point to the continued expansion of research in this area. This expansion is driven by ongoing technological developments and the pursuit of safer and more comfortable driving experiences. Further research could explore specific research areas within each country, the nature of collaborative projects, and emerging trends in lighting technologies.

The research conducted in this study has shown the importance of the colors of headlights for drivers, especially oncoming drivers, and that there are very few publications on the issues of glare caused by car headlights and, in particular, a clear need for further studies on these subjects. Further research into the color properties of headlights and their effects on drivers, especially regarding glare, holds significant potential for improving road safety and driving comfort. Understanding how different headlight colors affect visibility and perceived glare could lead to the development of optimized lighting systems that minimize discomfort for oncoming drivers while maximizing visibility for the vehicle operator. This could reduce accidents caused by glare-induced temporary blindness or impaired vision, particularly at night or in adverse weather conditions. Moreover, studying these factors could inform the creation of more ergonomic and user-friendly headlight designs, enhancing the overall driving experience and promoting safer roadways for all users.

Based on a bibliometric analysis, automotive manufacturers should concentrate on several key strategic areas to improve driving safety and comfort. These include accelerating the development and production of smart and adaptive lighting technologies, such as Smart Headlamp Systems and Adaptive Driving Beams, which have seen increased research focus recently. A critical aspect of this development is mitigating glare from high-luminosity LED and HID systems, requiring further research into the color properties of headlights and their impact on drivers to create systems that balance visibility with reduced discomfort for others. Furthermore, manufacturers should integrate sustainability and life cycle thinking into their designs, ensuring a balance between headlamp performance, environmental impact, and ecological considerations. Ergonomic and vehicle-type-specific designs are also crucial, focusing on user-friendliness and adapting headlamp features to different vehicle types and

driving scenarios. Finally, strengthening academic and international collaboration, potentially by partnering with key influential players identified in research networks, and leveraging methodologies like digital twins to optimize performance through accurate simulations, are recommended for accelerating innovation in automotive lighting.

Ethics Committee Approval
N/A

Peer-review
Externally peer-reviewed.

Author Contributions
Conceptualization: S.G.; Investigation: S.G.; Material and Methodology: S.G.; Supervision: S.G.; Visualization: S.G.; Writing-Original Draft: S.G.; Writing-review & Editing: S.G.; Author have read and agreed to the published version of manuscript.

Conflict of Interest
The authors have no conflicts of interest to declare.

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