Engineering Innovations
ISSN: 2813-1002, Vol. 11, pp 43-62
doi:10.4028/p-um3VJO

Submitted: 2023-12-01
Revised: 2023-12-24
Accepted: 2023-12-29
Online: 2024-06-26

A Bibliometric Analysis of Suspension System Development for Enhancing Comfort in Family Passenger Vehicles

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Keywords: Passenger comfort, suspension system, bibliometric analysis, suspension technology, development suspension

Abstract. In daily-used family passenger cars, passenger comfort is crucial. Vehicle suspension is a major factor in passenger comfort. A detailed suspension domain knowledge evaluation is necessary. Despite continual comfort technology advances, studies have yet to use bibliometric analysis to track suspension system history and expansion. This study analyzes keywords, citations, h-index, publishing years, journals, affiliations, nations, authors, and review articles in a novel way. Based on Scopus, the analysis is performed in CSV format and incorporated into bibliometric.org's Biblioshiny, VOSviewer, and R-studio apps. The US leads this study, followed by India and Canada. Indian publications are the most prolific. For suspension technology makers, this research may help them discover rivals and predict future trends. This study promotes suspending technology development through educated decision-making, strategic planning, and innovation.

Introduction

When crossing road surfaces, vehicles are familiar with roll movements when turning corners, pitch when braking or accelerating, and bounce when vibrating vertically due to following a bumpy road surface [1]. This phenomenon causes discomfort and can affect the safety of passengers. The car's active suspension system ensures adequate stability, maintains continuous road wheel contact, and improves suspension performance [2], [3]. The main function of the suspension system is to support the car body and then isolate the body from irregular road surface disturbances [4], [5]. In the active suspension system, the implementation of the control system plays a very important role in balancing the trade between driving comfort and handling [6]. Suspension systems in cars are classified into various types. In general, you will learn three types of suspensions, namely independent, dependent, and semi-independent. Independent suspension is a system where the left and right wheels are not in a rigid line. Independent suspension (rigid) occurs because the right and left wheels are in a rigid line. At the same time, the semi-independent suspension is a combination of rigid and independent suspension. More specifically, the automotive world recognizes the following types of car suspensions.

Macpherson suspension: This type is most widely used in light vehicles such as Sedans, MPVs, Hatchbacks, etc [7]. This type of front suspension is classified as an independent suspension type where the right and left wheels of the car are not adrift. Macpherson suspension is very good because it can dampen vibrations quite well. This type of suspension design is quite simple and does not take up space, so it is suitable for use on small cars. Macpherson has several components. Among these

components, a coil spring or coiled spring is used because it is minimalist in shape, and the elastic is quite flexible. Furthermore, a shock absorber is located inside the coil spring, so these two things are one component unit [8]. There is also a lower arm, which is a suspension arm that links the wheels and the car body. In addition, a ball joint or 360-degree hinge is located at the end of the lower arm, allowing the wheel to move in any direction as desired. Lastly, there is the knuckle arm and stabilizer. The knuckle arm is a place to put suspension components, such as lower arms, shock breakers, tie rods, and wheels. At the same time, the stabilizer is located in the shock absorber tube, which is connected to the knuckle arm.

Double Wishbone Suspension This type of suspension is widely used by crossover vehicles such as the Double Cabin and Big SUV [9]. This type of suspension is classified as independent of the type of front suspension. At first glance, the double wishbone suspension looks similar to the Macpherson. However, the double wishbone suspension design is more robust and complicated [10]. This suspension has two arms: the lower arm at the bottom and the upper arm at the top. These two suspension arms make the vertical movement of the wheels more balanced. Rigid suspension: This type can only be found on buses and trucks. This suspension includes a dependent suspension with the right and left wheels on a rigid block. This type of suspension can be located on the front or rear suspension. Rigid suspension has advantages in the level of durability. This type is the most powerful suspension capable of receiving large loads. This is because the rigid block where the right and left wheels are attached also supports the vehicle body. The rigid suspension also has several components, such as leaf springs, shock absorbers, rigid blocks, and stabilizer bars. For the first component, this spring is elongated and arranged in stages to increase spring strength.

Furthermore, a shock absorber is located between the rigid block and the car body. The rigid block or axle is a cross-shaped beam from the left to the right wheel, or it can also be called an ice block, and on the front wheel, this section uses a rigid axle. Multi-Link Suspension This type of suspension has several links. These links or links work like suspension arms but are three or more in number. The existing links are designed in such a way that they can support the movement of the wheels while dampening vibrations. Torsion Beam Suspension Torsion beam suspension is also known as semi-independent suspension [11]. This suspension has a basic design, such as a rigid suspension, which is innovated in such a way as to produce a better suspension effect. The basic form of an elongated rigid suspension is innovated to resemble the letter H. This shape makes the left and right wheel swings somewhat free. This will make the car more comfortable to drive. The elasticity possessed by the spring is used to dampen all the vibrations generated by the wheels due to the road surface. The suspension works as a barrier to the collision of the wheels with the car body.

Suspension Components The suspension system's main component is a steel spring, which is elastic and strong. This spring is later used to absorb vibrations on the road surface. However, the suspension components are not only springs. Several other components support it. Here are some of them. The suspension arm is a liaison between the wheels and the car chassis. This component is made of hinges, which can later be moved vertically. This vertical movement will help the wheel to move up or down, depending on the load received by the wheel. Shock Absorber's main function is to dampen the shock of the car's suspension, as the name implies. The suspension uses springs as its main component, but this spring has the disadvantage of having a return power when pressed. This will cause the car body to sway or oscillate despite no vibration. This component will prevent this from happening and can be used to prevent sudden spring movement. Shock absorbers can make the suspension effect harder and keep it stable because they can absorb shock effects well. This also causes no shock to the car—car-stabilizer, whose function is to balance the car body when the suspension works. Simply put, the car will lean outward when turning due to centrifugal force. This force can cause the car to roll over. Stabilizer serves to prevent and overcome this. This component also keeps the car in a safe and controlled condition.

Currently, many researchers are researching to improve the suspension system's performance. Using a quarter-car model, present an analysis of the ride comfort and road holding of passive and semi-active suspension systems [12]. The semi-active suspension system with magnetorheological (MR) damper is modeled as a non-parametric model-based magnetic flux density in the fluid flow gap [13]. Nagarkar et al. [14] presented the modeling, control, and optimization of a nonlinear quarter

car suspension system. A nonlinear quarter car mathematical model and seat and driver were developed and simulated in the Matlab/Simulink environment [14]. Ebrahimi et al. [15] compared the effects of various damping coefficients and spring stiffness values to identify which combination led to better suspension system performance. They developed a versatile semi-active suspension system with variable stiffness magnetorheological elastomer (MRE) isolator (VS) and variable damping magnetorheological (MR) damping (VD) for high-speed trains, aiming to improve ride comfort by avoiding body resonance car and eliminate vibration energy [16]. The quality of the set of vehicle suspension springs is relatively small, the displacement in the vertical direction is relatively small, and the turnaround time is relatively short. So, if you want to achieve the same vehicle suspension effect as the offering vehicle, we need to optimize the suspension parameters. The approach in this paper can also be used to make dynamic analysis for 1/2 suspension and whole suspension. Optimization of system characteristics is the right step to overcome excessive control force. Therefore, this paper is expected to provide information regarding the bibliography of the system on the car suspension that has been developed so far.

Methodology and Data Sources

The analysis is based on publications related to “suspension” published from 2000 to 2022. Literature was obtained through Scopus.com, with the search formulas for “suspension”, “car”, and “calculation” displaying document types from the related field. The results were from 2000 to 9 August 2022, with 1003 documents from the Scopus.com dataset using Vosviewer and R-studio Biblioshany from bibliometric.org [17].

Result

The data shown in Table 1 were obtained from an overview using R-studio Biblioshiny from bibliometric.org. From the main information menu, you can also see the development of productivity, making a journal about this suspension as the growth speed of the suspension can be seen in the annual scientific production year graph (Fig. 1) [18].

Table 1 Main Information Overview

Description	Results
2	2000:2022
Sources (Journals, Books, etc)	472
Documents	1003
Annual Growth Rate %	11.69
Document Average Age	7.58
Average citations per doc	21.5
References	37201
Keywords Plus (ID)	6764
Author's Keywords (DE)	2726
Authors	2708
Authors of single-authored docs	68
Single-authored docs	84
Co-Authors per Doc	3.66
International co-authorships %	13.86
Article	616
Book	8
Book chapter	20
Conference paper	312
Conference review	13
Retracted	1
Review	32
Short survey	1

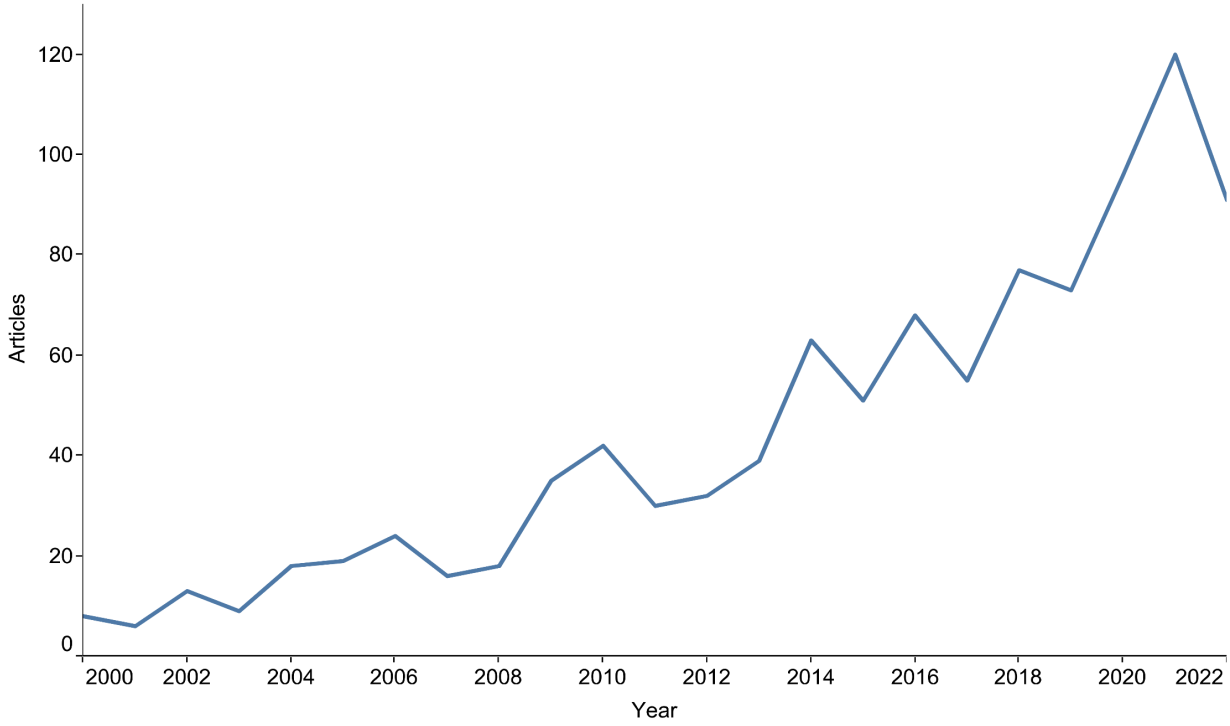

Fig. 1 Graph of Annual Scientific Production

Using the overview menu on this three-field plot unit, we can reference data based on the inputs in this case so that later, the data displayed is the most 20 or the best of the resulting plots (Fig. 2). In this case, the author will try to compile how an author in the middle refers to previous journal authors for digitizing in the left column and then using keywords on the right [19].

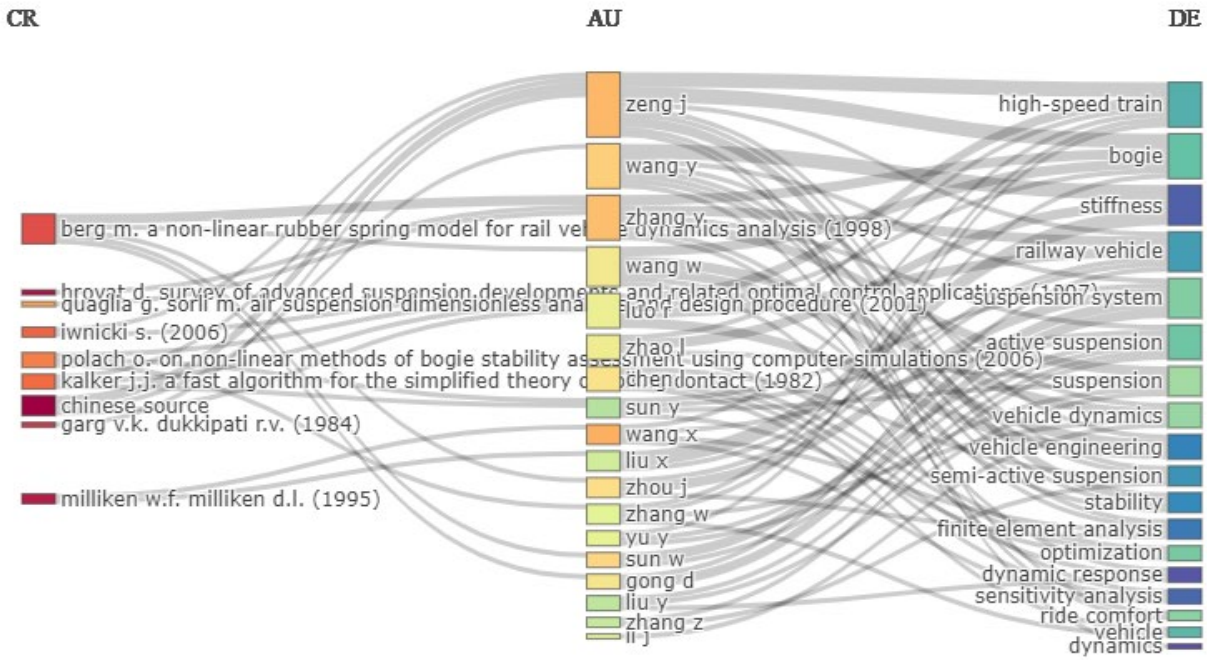

Fig. 2 Three Field Plot Reference-author-keywords

With the source menu in the most relevant source unit, we can see that the SAE technical paper is the one that appears the most, 56 times, followed by IOP conference series materials science and engineering in second place with 29 and vehicle system dynamics as many as 25 (Fig. 3). The connection between the selection of these sources is due to the habit of writing or the availability of

journal writing regarding suspension, bed linen; as we know, journal writing is also the result of the collaboration of the author and their writing habits, so that the selection of appropriate sources and the terms and conditions of publication are carried out by sources providing scientific journal publications.

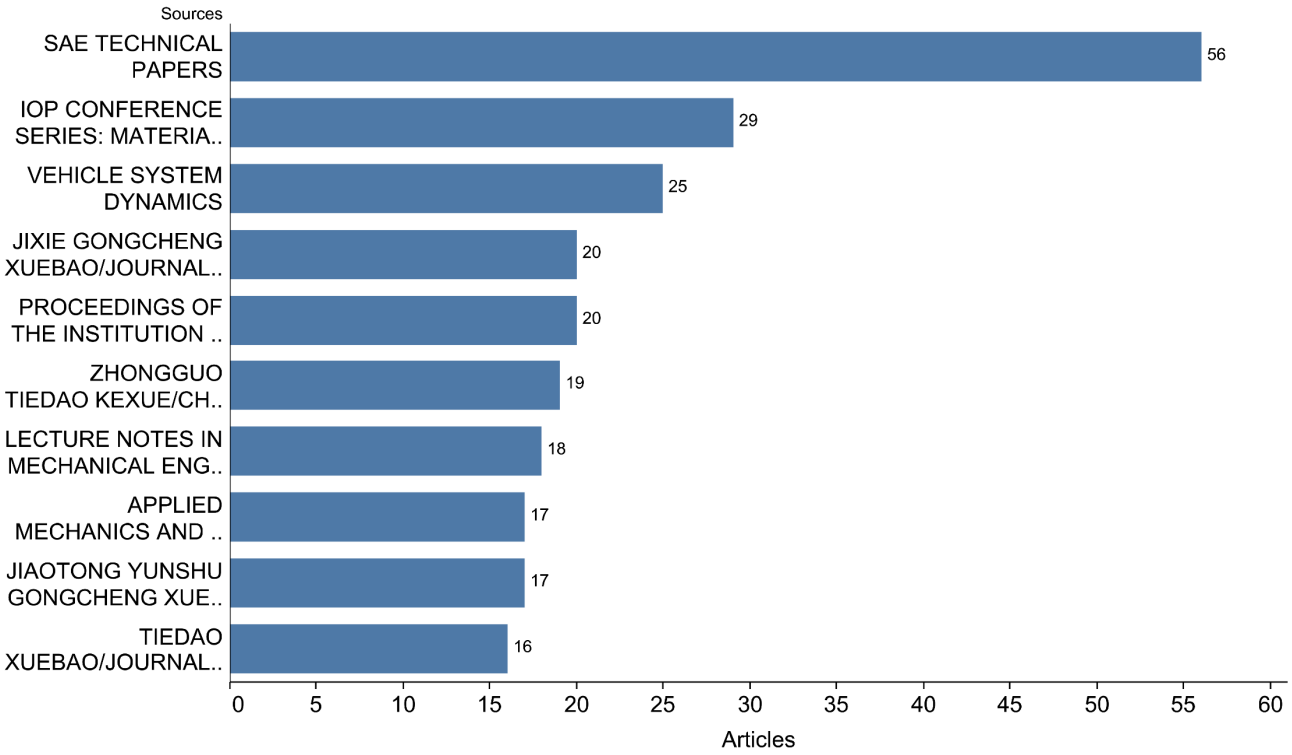

Fig. 3 Most Relevant Source

With the source menu in the most locally cited source unit, we can see that Computer Simulation Of Liquids: Second Edition are the most common with 6044 citations, followed by Biomacromolecules in second place with 2082 times and Vehicle System Dynamics with 864 times (Fig. 4). In the source menu, we can also see source impact in Fig. 5, and get the h-index, g-index, and m-index tables as well as the number of citations which will be shown in Table 2 and source dynamics in Fig. 6.

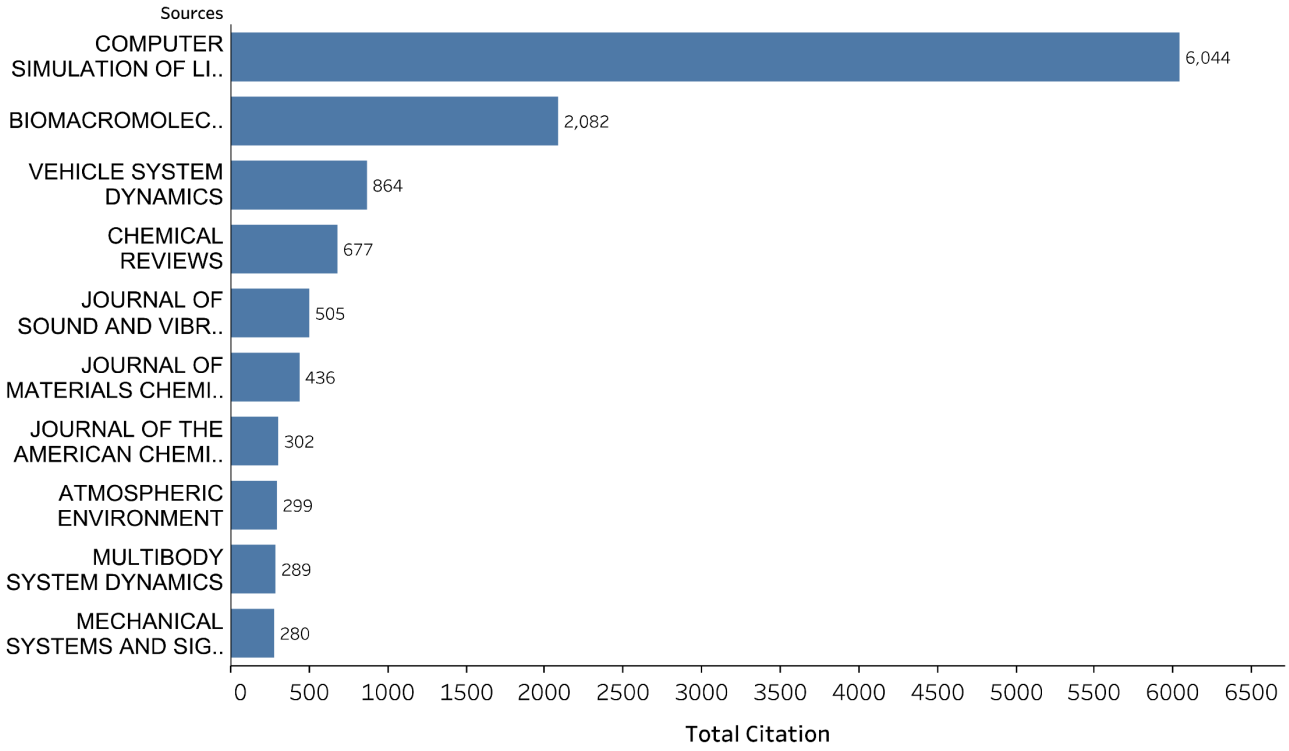

Fig. 4 Most Locally Cited

Table 2 H-index, g-index and m-index Tables

Element	h_index	g_index	m_index	TC	NP	PY_start
VEHICLE SYSTEM DYNAMICS	16	25	0.696	864	25	2001
JIXIE GONGCHENG XUEBAO/JOURNAL OF MECHANICAL ENGINEERING	9	11	0.600	161	20	2009
JOURNAL OF SOUND AND VIBRATION	8	9	0.364	505	9	2002
PROCEEDINGS OF THE INSTITUTION OF MECHANICAL ENGINEERS, PART F: JOURNAL OF RAIL AND RAPID TRANSIT	8	12	0.615	181	12	2011
INTERNATIONAL JOURNAL OF AUTOMOTIVE TECHNOLOGY	7	7	0.500	121	7	2010
MECHANICAL SYSTEMS AND SIGNAL PROCESSING	7	7	0.875	280	7	2016
PROCEEDINGS OF THE INSTITUTION OF MECHANICAL ENGINEERS, PART D: JOURNAL OF AUTOMOBILE ENGINEERING	7	13	0.318	181	20	2002
SAE TECHNICAL PAPERS	7	9	0.292	154	56	2000
TIEDAO XUEBAO/JOURNAL OF THE CHINA RAILWAY SOCIETY	6	11	0.353	136	16	2007
ZHONGGUO TIEDAO KEXUE/CHINA RAILWAY SCIENCE	6	10	0.300	133	19	2004

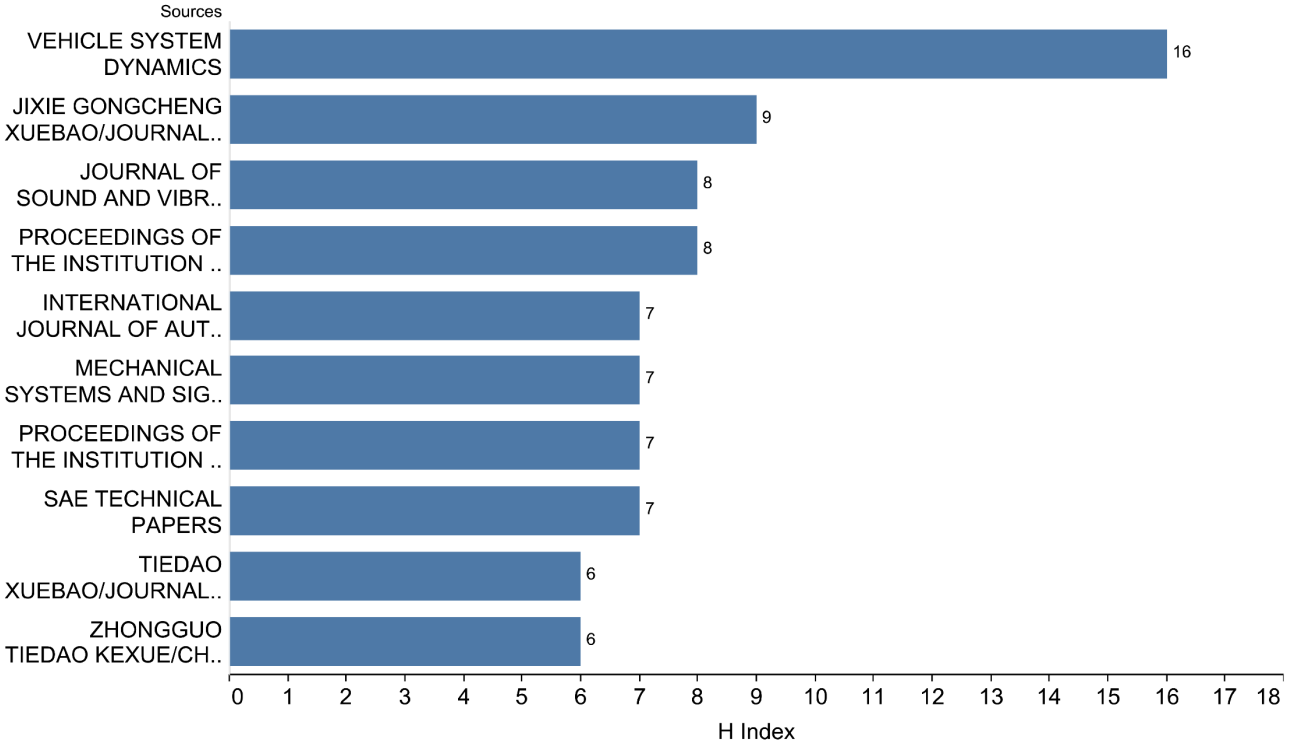

Fig. 5 Most Local Impact

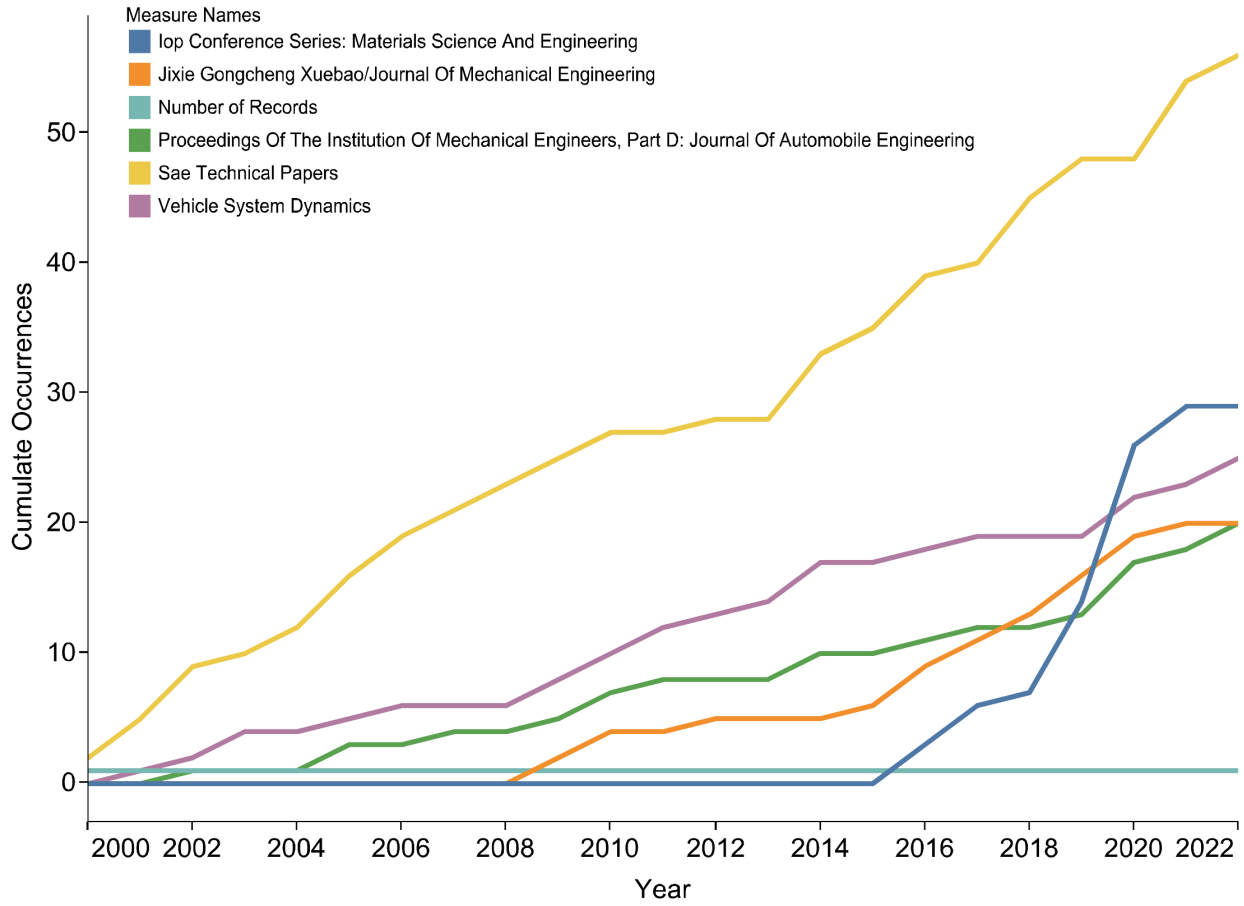

Fig. 6 Source Dynamics

In this author menu, select the most local and relevant citations, author production over time, author influence, related author affiliations, country scientific production, and most cited countries. This menu will discuss which countries have published the most scientific papers regarding the keyword suspense. The countries that published the most scientific journals about this suspension were China 1,557 times, the United States 224 times, and India 171 times. Here, we present the countries that will publish their journal production in Table 3. The author's menu yields the most relevant author units and the most locally cited author units, as shown in Fig. 7 and 8.

Table 3 Most Local Impact

Region	Freq
CHINA	1557
USA	224
INDIA	171
ITALY	127
SOUTH KOREA	118
UK	101
GERMANY	97
POLAND	93
JAPAN	64
CANADA	55

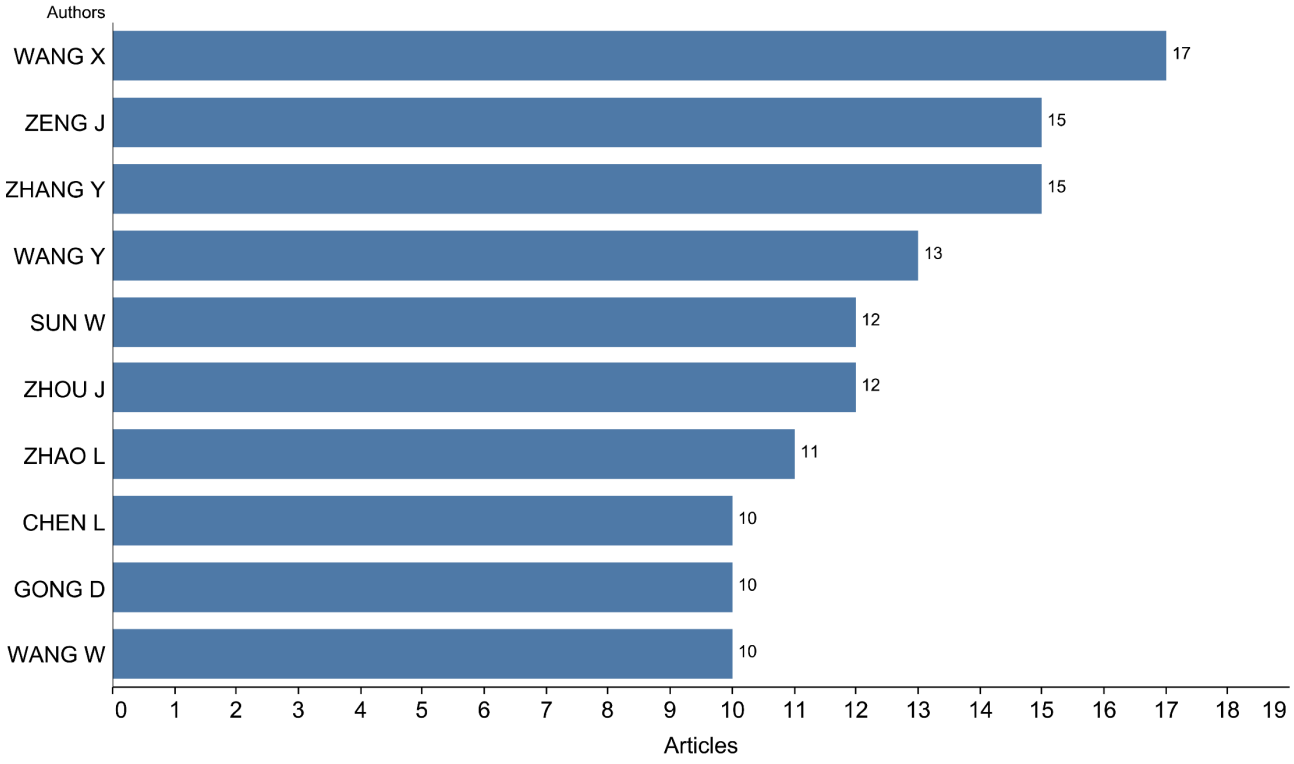

Fig. 7 Most Relevant Author

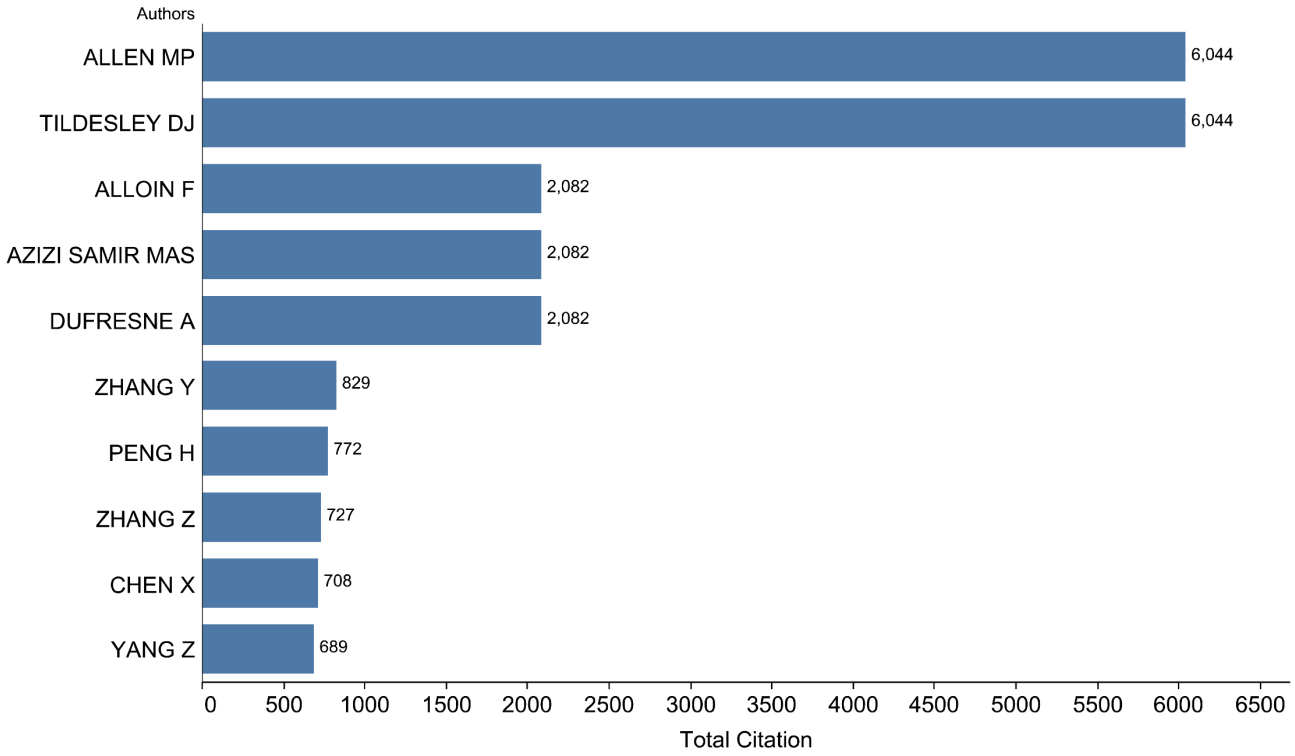

Fig. 8 Most Locally Cited Author

This discussion is an interesting topic where the document menu will display several sections that can be explained in the bibliography so that the journal's quality will appear based on citations carried out by the next author. This number of citations impacts the author so that the value of the h-index, m-index, and g-index will increase as the citations obtained by the author increase from the citations obtained [20]. The following are the top 10 Most Global Cited Documents with the top 10 best rankings where Allen MP was ranked first for 6044 citations, followed by Azizi Samir Mas, in second place with 2082 times and Yang Z, 677 times (Fig. 9).

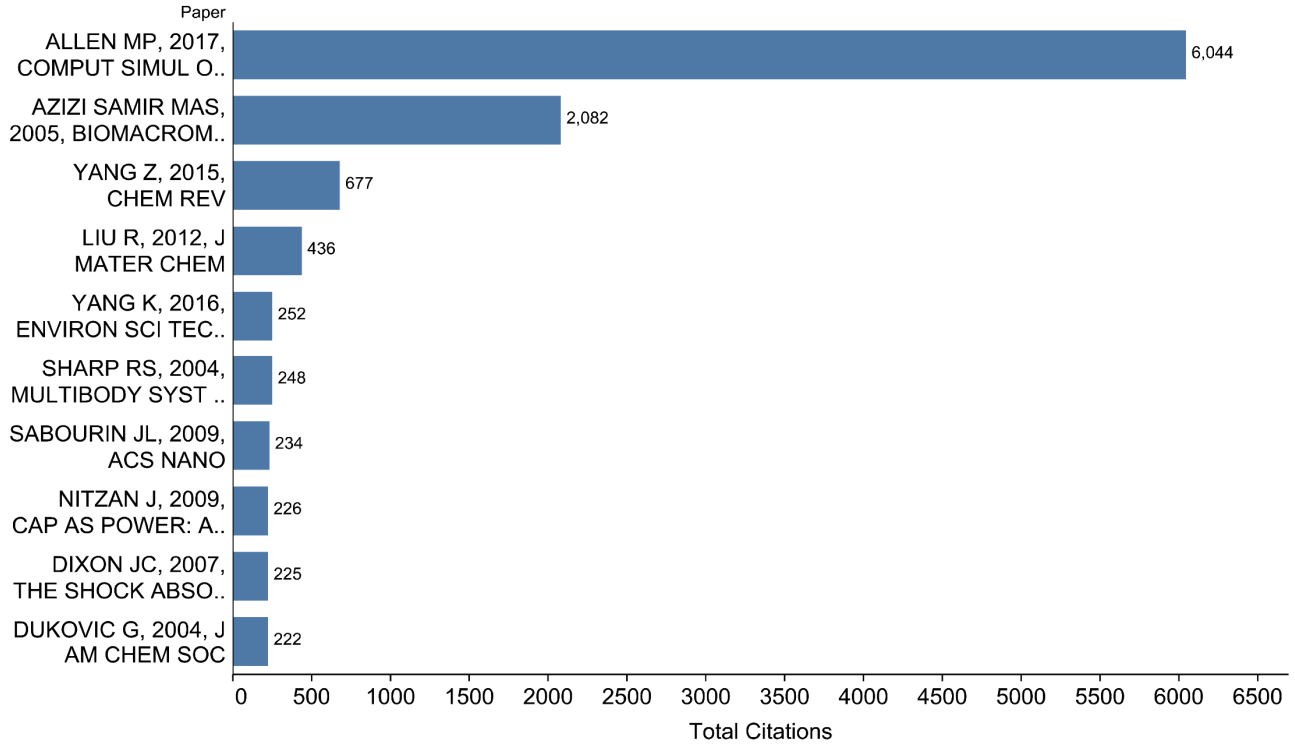

Fig. 9 Most Global Cited Document

Fig. 9 shows keywords that the writer uses in determining keywords, making it easier for future writers to write every future article. For keywords that the author often uses, suspension ranks first, which was made 32 times, then ride comfort 26 times, then vehicle dynamics 26. In the data displayed, the suspension (components) will come first on the subtopic discussion of self-suspension. Here, we show the most relevant word in Fig.10, word cloud in Fig. 11, and the tree map in Fig. 12.

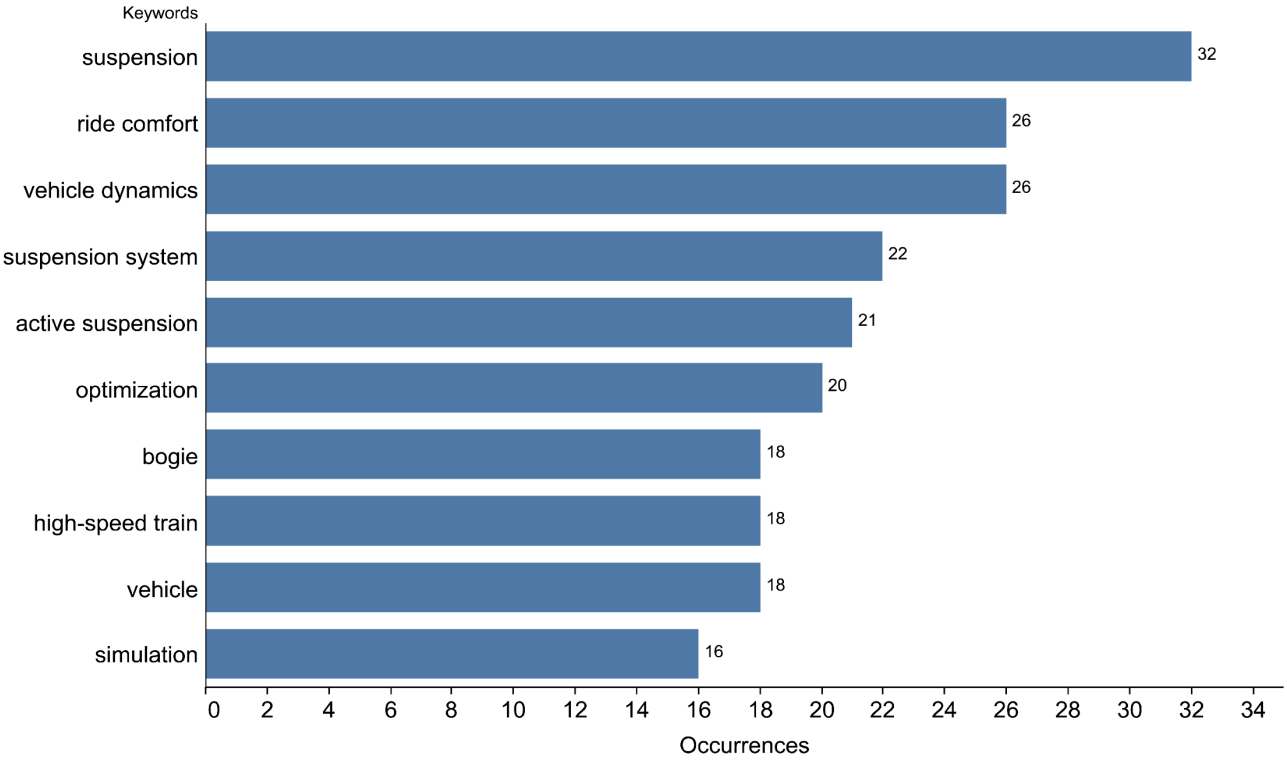

Fig. 10 Most Relevant Words

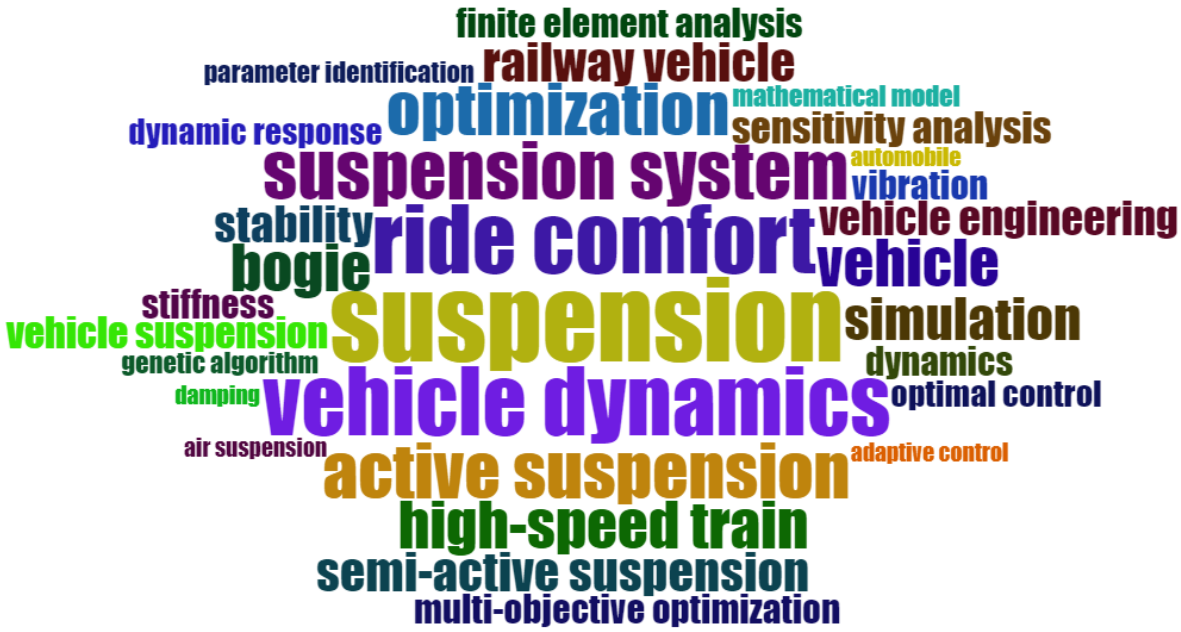

Fig. 11 Word Cloud

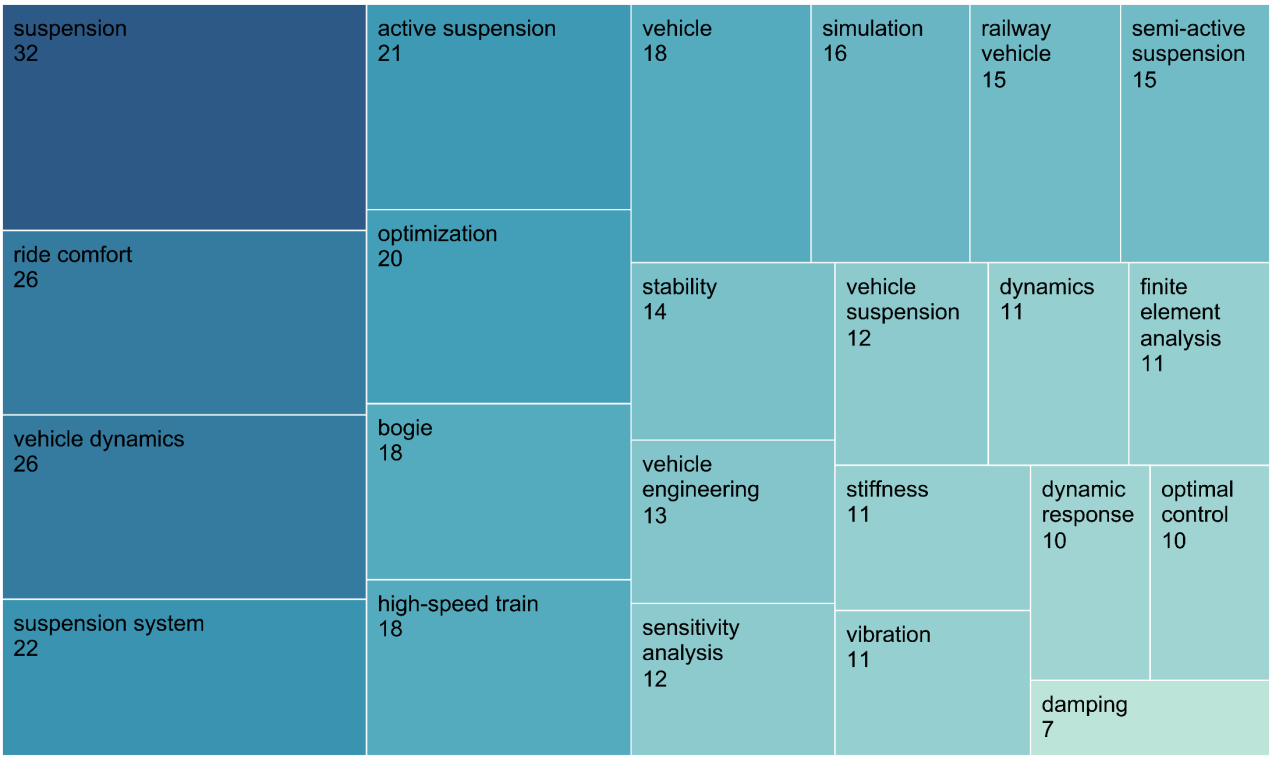

Fig. 12 Tree-map

In the conceptual structure menu, we can see the co-authors' role through the development of scientific journal writing, where not all co-authors focus on writing suspension journals. These co-authors act as people who provide suggestions and ideas to the author in writing scientific journal publications. Different backgrounds will further add to and open up new gaps in writing pending scientific journal publications.

Next, to see the development of journal writing based on keywords, we can see the development of journal writing by looking at its conceptual structure, where in the picture, the conceptual data on the development of journal writing based on existing keywords will be displayed. Fig. 13 will be displayed in the conceptual structure map. The term factorial map is in Fig. 14, the most contributed map is in Fig. 15, and the most cited map is in Fig. 16.

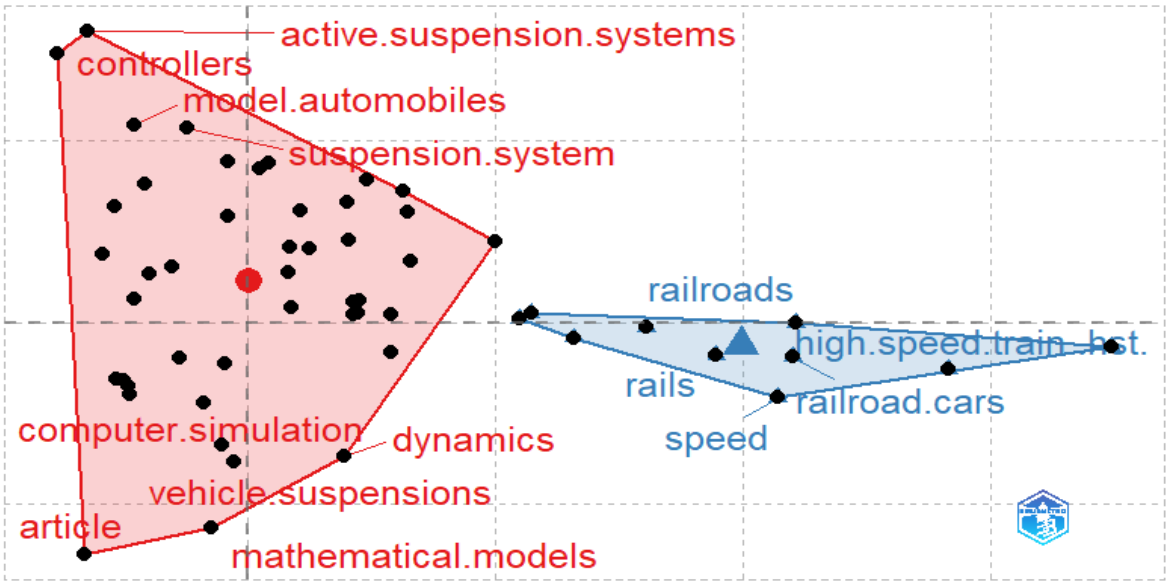

Fig. 13 Conceptual Structure Map

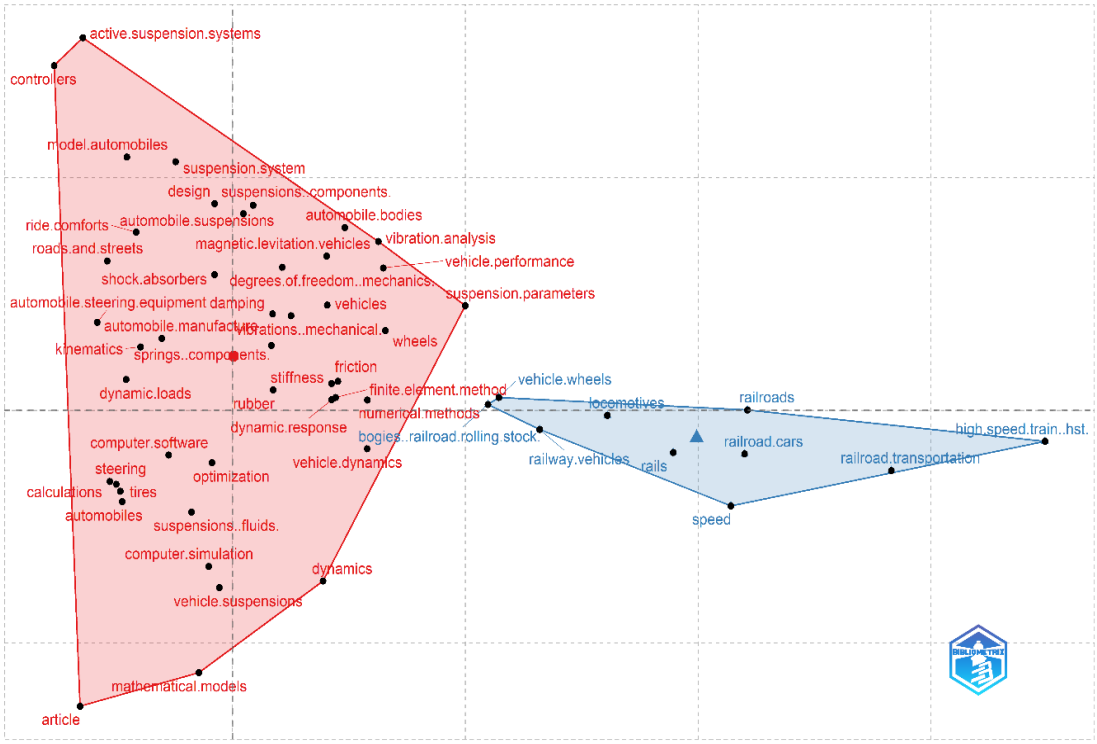

Fig. 14 Term Factorial Map

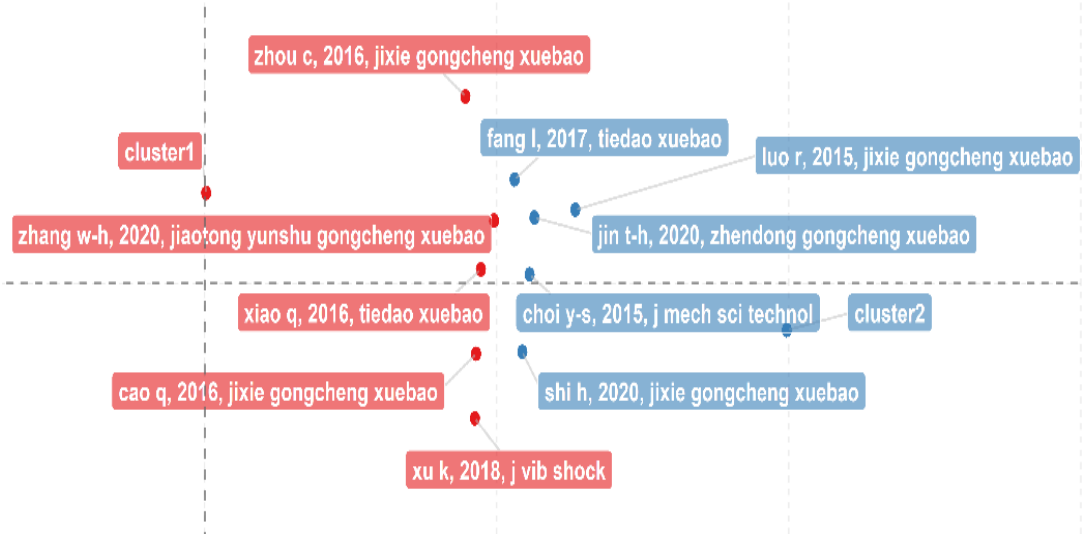

Fig. 15 Factorial Map of the Documents with the Highest Contribution

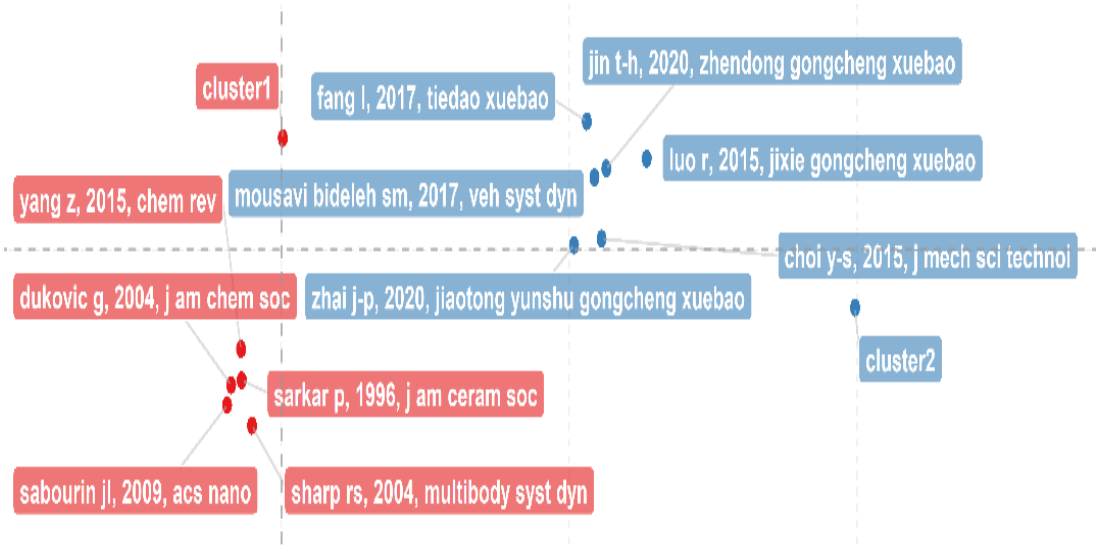

Fig. 16 Most Cited Map

In the conceptual structure, we can see how it develops based on keywords so that new keywords are linked to keywords or journals cited to illustrate the development of scientific writing journals published as a thematic evolution. In this thematic evolution, we can see the timeline mapping of journal development by looking at the timeline, the thematic evolution network, and evolution data and keyword clusters in the development of journal writing.

In the conceptual structure of the co-occurrence structure unit, we can see the relationship between the use of existing keywords (Fig. 17); this will continue to increase the number of existing keywords and give rise to new keywords to fill existing gaps seen in the network (Fig.18).

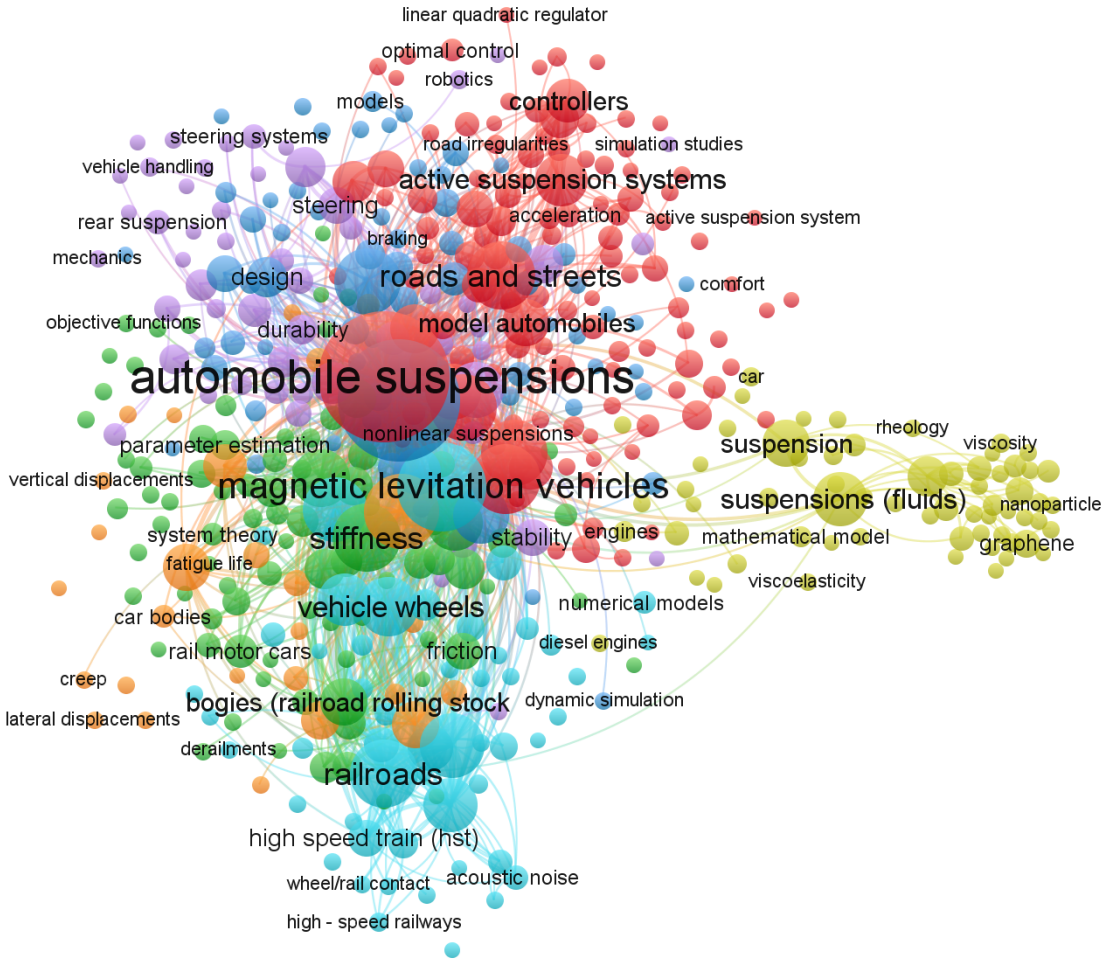

Fig. 17 Co-occurrence Network

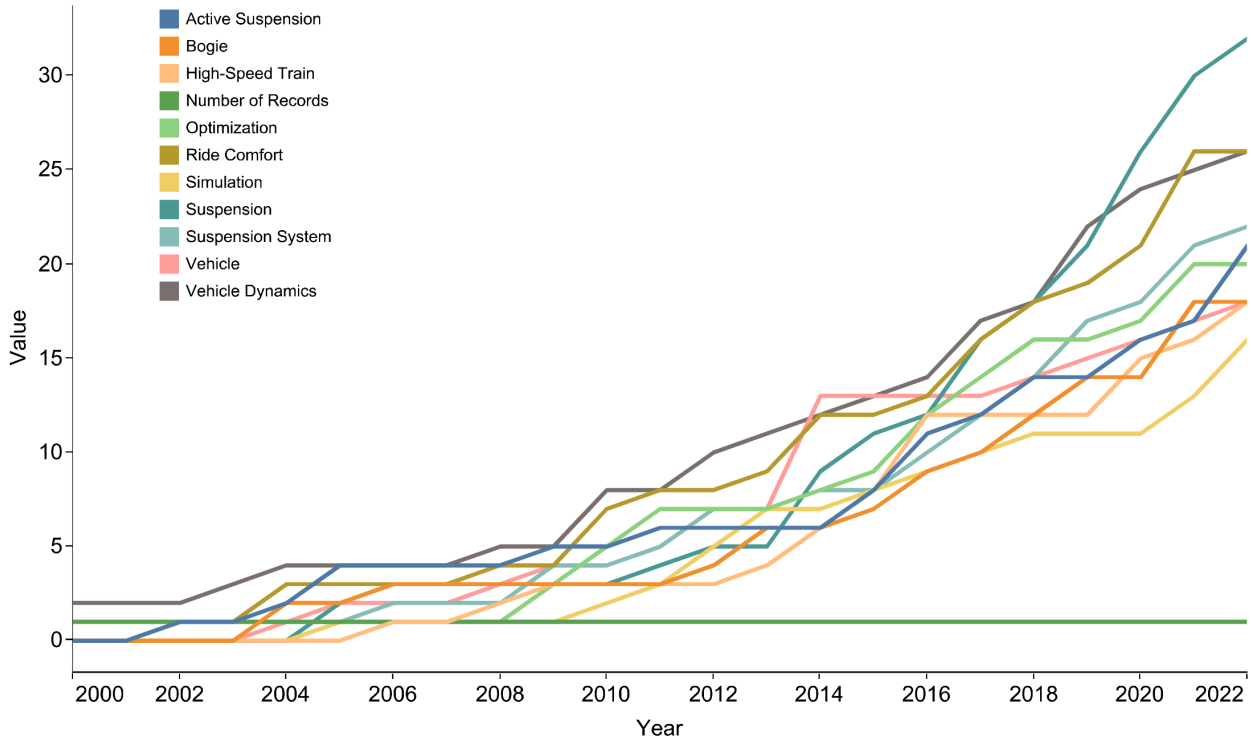

Fig. 18 Word Dynamic

It will be very interesting to look at the bibliography of journal writing about suspension from using these keywords; later, we will find out how the word coupling is used. We will be able to find developments about writing suspension journals and how the technology develops by looking at word coupling to see and determine existing and new gaps, or we will add gaps to gaps that have been created (Fig. 19).

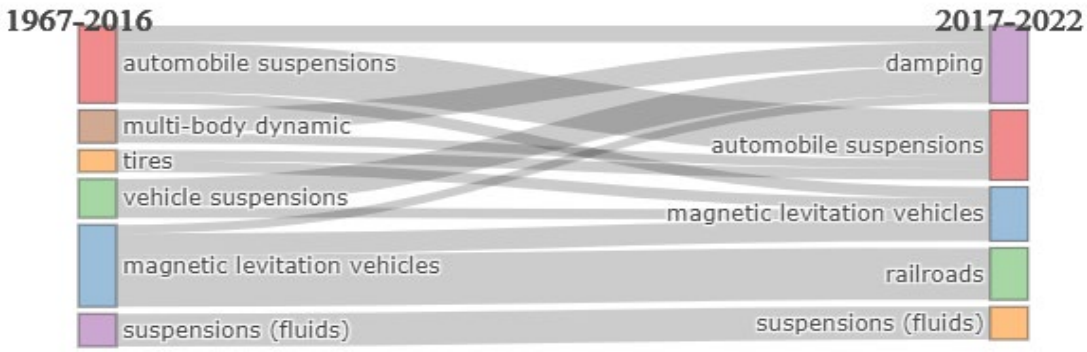

Fig. 19 Thematic Evolution

In the intellectual structure menu of the co-citation network unit, we can see the relationship between citation collaborations based on existing authors (Fig. 20), including papers (Fig. 21) and sources (Fig. 22).

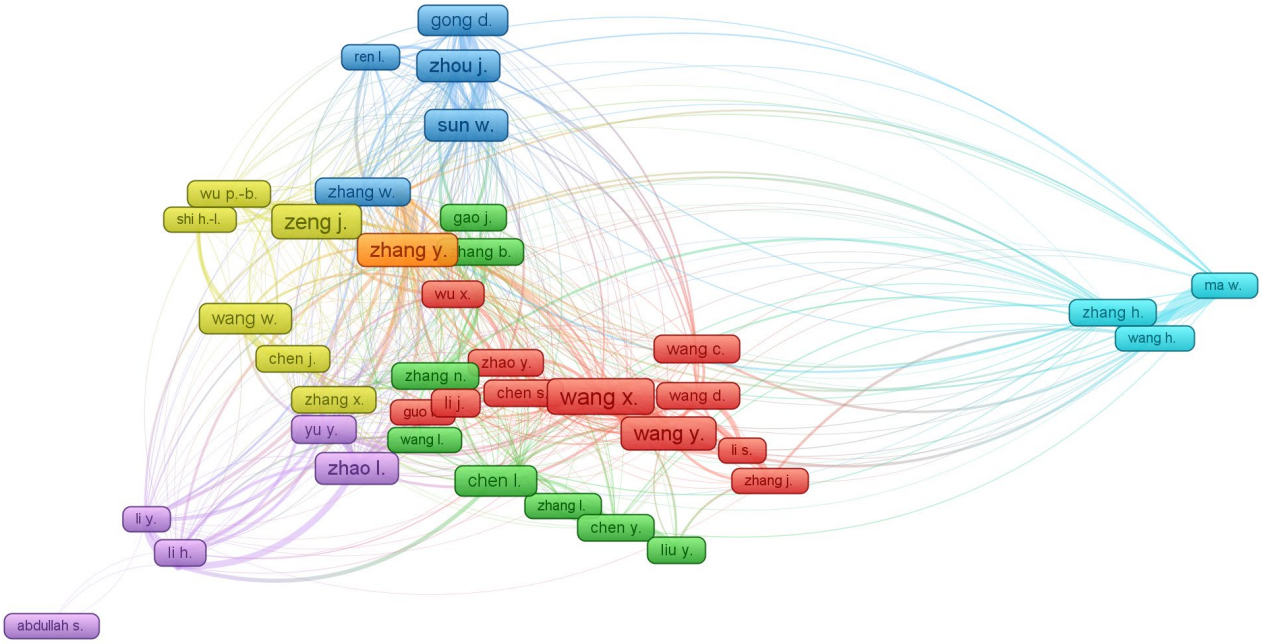

Fig. 20 Co-conceptual Structure – Author

Fig. 21 Co-conceptual Structure – Paper

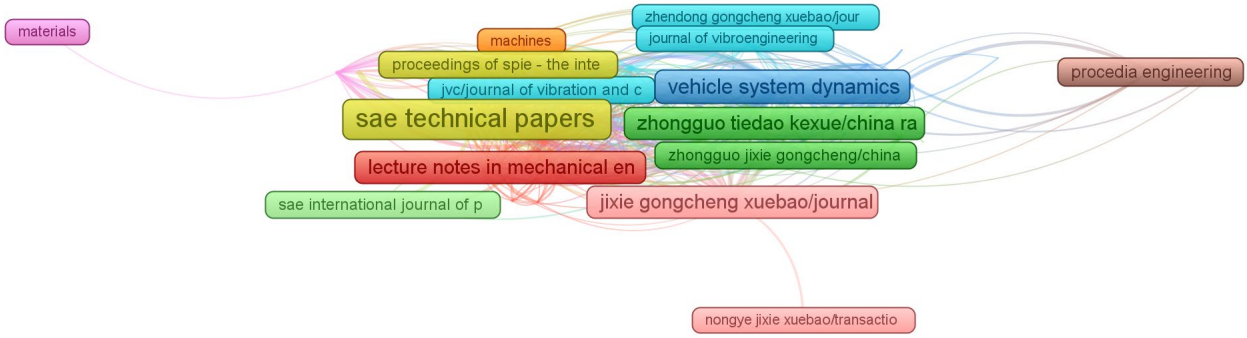

Fig. 22 Co-conceptual Structure – Sources

In the collaboration network menu, we can see the network formed from collaboration in writing scientific journals. As we know, most scientific journal authors are academics or professionals. Therefore, this collaboration is a place for authors to conduct studies or work for agencies or companies to establish good collaborative relationships. Promote the development of scientific journal writing by the author's interest in scientific interests. This development occurs when there is a relationship between the author and other authors so that they become co-authors (Fig. 23), the author exchanges studies at other institutions (Fig. 24), or the writer is developing in another country so that a network can be formed that can be presented (Fig. 25). So that from the social structure, the exchange of ideas and knowledge can be obtained in the development of journal publication writing which is depicted by the world collaboration map (Fig. 26).

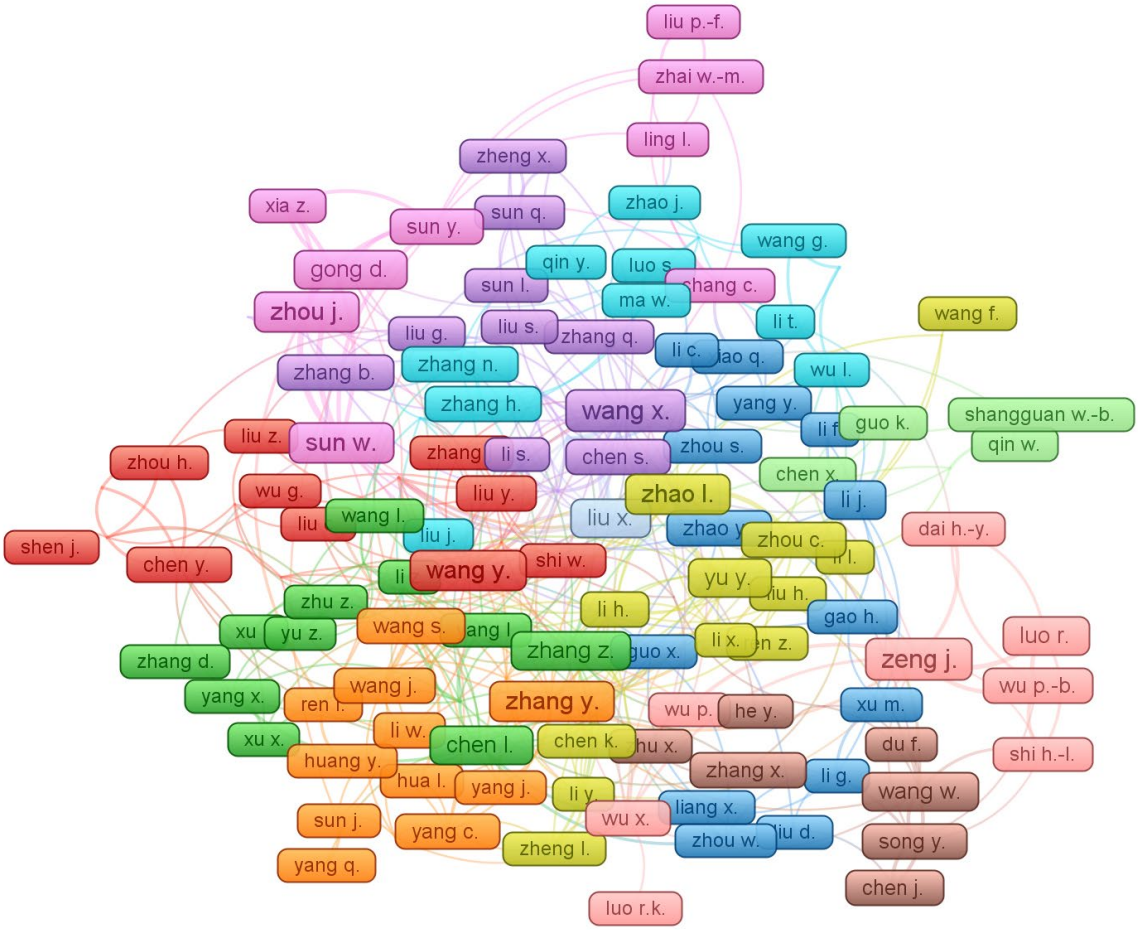

Fig. 23 Collaboration Network Author

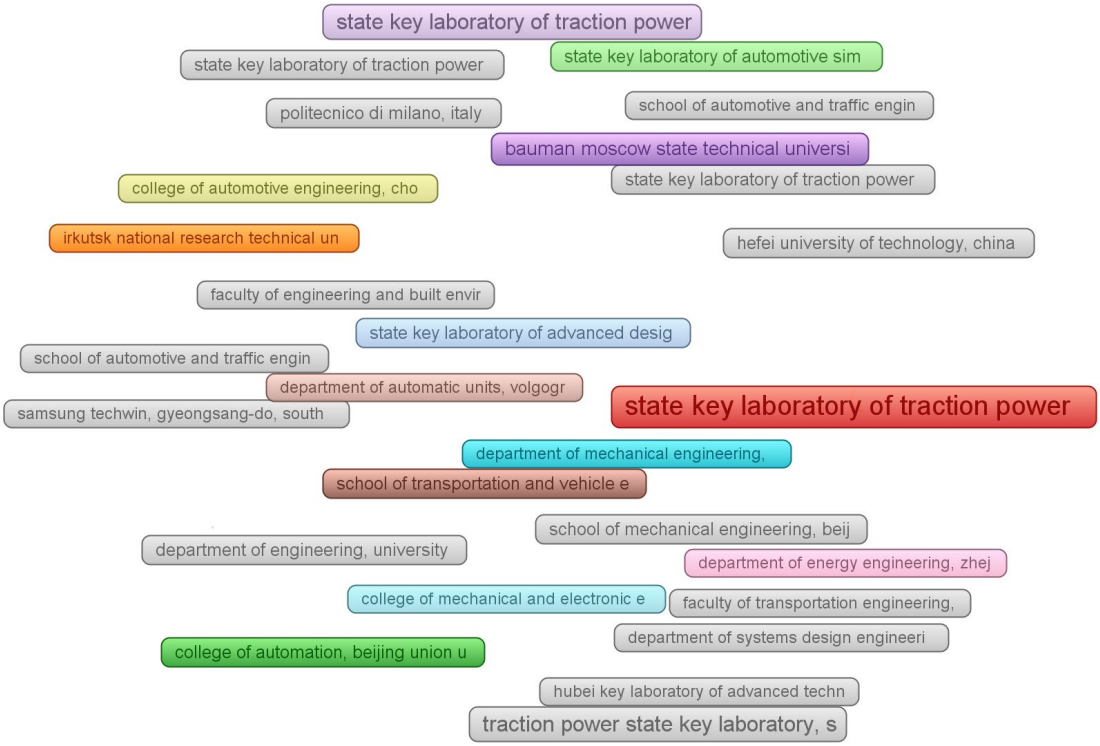

Fig. 24 Collaboration Network Institution

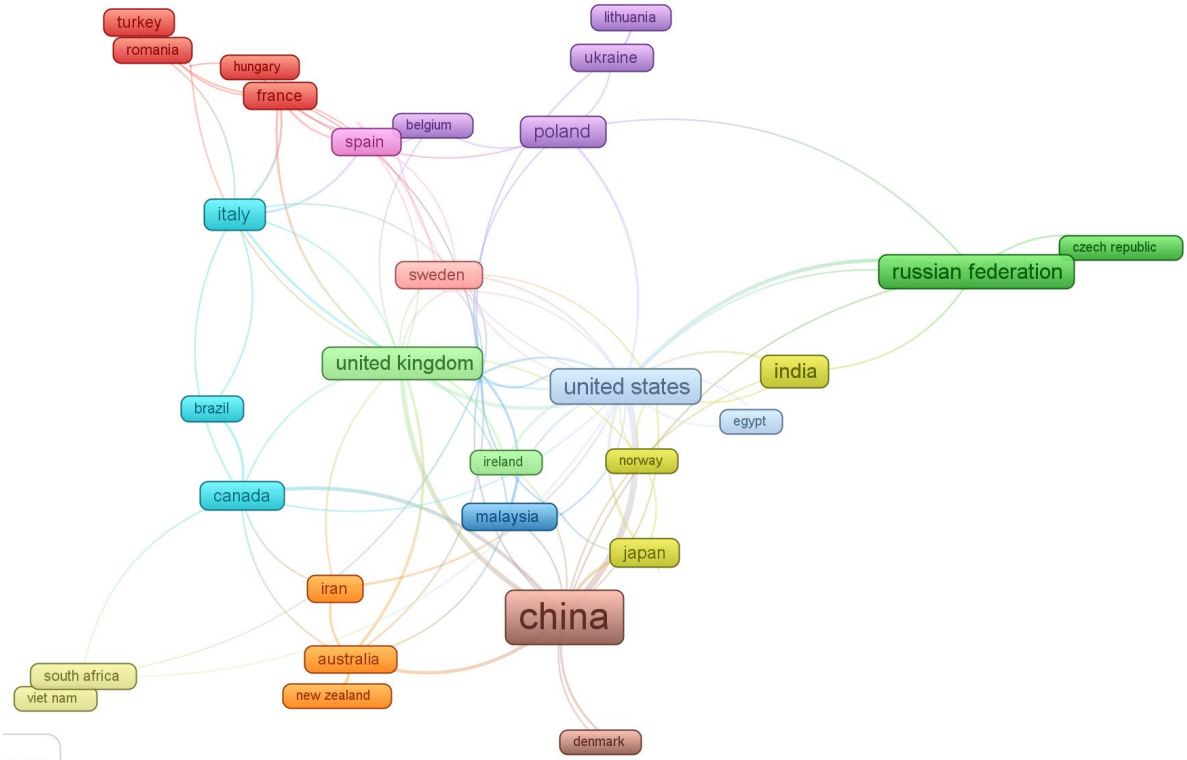

Fig. 25 Collaboration Network Country

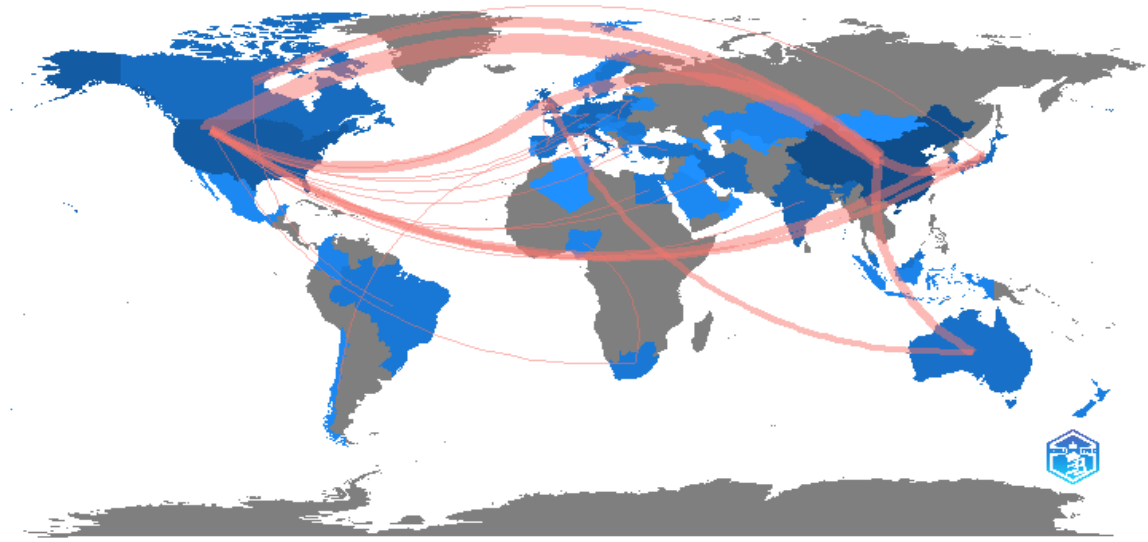

Fig. 26 Image of Country Collaboration Map

Discussion

The critical importance of passenger comfort, particularly in family vehicles subjected to daily use, underscores the need for comprehensive examination. The suspension system is very important among the many factors that influence comfort. Therefore, this paper emphasizes the need for a comprehensive review of the existing knowledge base in the suspension domain. Despite the progress in suspension technology, a notable void persists due to the absence of prior research incorporating historical evolution and growth analysis using bibliometric techniques.

The paper introduces an innovative method, showcasing an intricate analysis encompassing keywords, citations, h-index, publication years, affiliations, and more. This analysis is based on the esteemed scopus.com database, processed and integrated into applications offered by bibliometric.org. The outcomes reveal the United States as a dominant force in suspension research,

closely trailed by India and Canada. The implications of this study extend to suspension technology developers, offering insight into competitors and emerging trends. As a result, this research enables decision-making, strategic planning, and innovation in suspension technology development.

Additionally, this research provides a global overview of contributions to anti-ballistic technology. Notably, China emerged as a significant contributor, surpassing the United States in several publications, raising questions about potential technological shifts. However, it will raise questions about China's rising prominence and potential future technological leadership. In conclusion, the paper underscores passenger comfort's relevance in vehicular travel, especially for family vehicles. The paper's bibliometric approach fills knowledge gaps, offering valuable insights to practitioners and researchers and facilitating strategic decisions and innovation. Additionally, the study's focus on anti-ballistics technology highlights China's presence, prompting considerations about future technological trajectories and shifts in global leadership.

Future Implications and Prospects

Future developments in automotive technology are expected to be driven by efforts to achieve better passenger comfort in family passenger vehicles. In a contemporary period characterized by an increasing desire for an uninterrupted travel experience, the importance of suspension systems in facilitating such comfort has become increasingly clear. So, a thorough assessment of the current knowledge is required.

Nevertheless, despite the continuous advancements in suspension comfort technology, a notable study deficiency is attributed to the absence of historical perspectives offered by bibliometric analysis. Addressing this void can enhance our comprehension of the progression of suspension systems and stimulate novel perspectives and advancements. By utilizing novel approaches and bibliometric tools, forthcoming scholars can delve further into the historical progression of suspension systems, thereby uncovering intrinsic trends and patterns that influence their evolution.

The results of this analysis, which emphasize the prominent positions of the United States, India, and Canada, provide a basis for possible collaborations and the sharing of information across borders. The discovery above, in conjunction with China's involvement in anti-ballistics technology, raises thought-provoking questions on the dynamics of global technical supremacy. Subsequent investigations may explore the ramifications of these patterns on global alliances, the dissemination of technology, and cooperative enterprises.

This study establishes a foundation for a promising trajectory in vehicle technology research. The text urges researchers, industry executives, and legislators to actively involve themselves with historical viewpoints and utilize data-driven insights to design a transportation future that is both technologically sophisticated and provides enhanced comfort. This study reiterates the significance of passenger comfort and suspension systems while promoting a proactive mindset that embraces innovation, collaboration, and prospective changes in global technology environments.

Conclusion

This study highlights the importance of prioritizing passenger comfort, particularly in family vehicles regularly subjected to extensive daily usage. The importance of the suspension system in ensuring passenger comfort underscores the need for a thorough examination of suspension-related information. Despite the significant progress made in suspension technology, a notable void exists in the literature pertaining to the historical examination of this field utilizing bibliometric methodologies. This research presents a novel methodology that utilizes the scopus.com database to analyze essential dimensions, which are afterward integrated into bibliometric.org tools.

The study's findings demonstrate the United States' prominent position in suspension research, with India and Canada following suit. India has emerged as a noteworthy participant in suspension technology development, providing valuable insights for developers by recognizing competitors and discerning emerging trends. This study provides valuable insights for decision-making, strategic planning, and fostering creativity. Furthermore, this research delves into the realm of anti-ballistics

technology, particularly emphasizing China's prominent position in this field. This investigation prompts inquiries regarding potential forthcoming technological transformations.

This study emphasizes the significance of suspension, explains the utilization of bibliometric analysis, and offers valuable insights for developers. It facilitates the cultivation of well-informed decision-making, strategic planning, and innovative thinking while concurrently prompting thoughtful reflection on technological trends and changes in global leadership. Using bibliometric analysis is a valuable instrument for prospective researchers to forecast trends and enhance suspension technology.

Funding Information: The authors state no funding involved.

Author Contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Conflict of Interest: The authors state no conflict of interest.

Data Availability Statement: All data generated or analyzed during this study are included in this published article.

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