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Article

Trends and critical points in maintenance management for MSMEs: a bibliometric review

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Abstract: . This study presents a bibliometric review related to maintenance management in SMEs, based on 174 scientific articles published in Scopus and Web of Science, between the years 1992 and 2025, related to the search criteria maintenance management, predictive maintenance, preventive maintenance, maintenance engineering, maintenance strategy, SMEs, the study applies a hybrid methodology through the use of tools such as R Studio – bibliometrix and VosViewer, with the aim of processing bibliographic data from scientific publications to obtain trends such as the average number of citations per document (10.63), number of citations per document (3.28), authors (469), references (4908) which allows us to relate the keywords, identify trends and patterns. The results show that from 2018 onwards there has been an increase in production due to technological, economic and social changes related to improved productivity, competitiveness and sustainable maintenance. India and the United States lead with the highest number of publications, while institutions such as AMS Technology Center, Kalasalingam University, and Punjabi University stand out. Maintenance management in small and medium-sized enterprises ensures operational continuity, improves product quality and image, and should therefore be considered a strategic investment, provided that adequate planning and scheduling are taken into account depending on the type of company, Human talent management, control, and monitoring face challenges due to budgetary constraints, as it is often viewed as an expense rather than an investment, and as a reactive approach that prioritizes fixing problems instead of preventing them. This study identifies research conducted in different contexts and regions.
Keywords: Maintenance, predictive maintenance, SMEs, preventive maintenance, maintenance strategies, maintenance management.

1. Introduction

The world's economy moves through the business sector, organizations are classified as large, medium or small depending on their organizational size and volume of operation, the set of small and micro enterprises are known as MSMEs [1], the number of this type of organizations in the different countries is high, representing a considerable percentage, so that in Ecuador the participation segment is 93.7% according to data from the National Institute of Statistics and Censuses [2].

One of the main challenges of MSMEs is maintenance management, because for a long time it was considered an operational activity, which was not linked to the administrative system of organizations, but has now changed to become a key function in production operations [3]. Maintenance management involves having activities aimed at maintaining the useful life of the equipment in optimal operating conditions to avoid unforeseen failures [4] in the machines that are in the operational processes.

In several MSMEs, preventive maintenance programs or review schedules, which generates unexpected operational failures, stoppages and loss of production, this absence translates into high costs and low efficiency [5], which is why it is necessary to have adequate maintenance management in organizations, which must be supervised and improved based on process indicators.

The purpose of this research is to carry out a bibliometric review of articles related to maintenance management in MSMEs and to verify the relationships and collaborations between educational institutions in the various countries.

2. Methodology

For the execution of the research, a bibliometric analysis was carried out focused on maintenance management in small and medium-sized companies, the data collection was carried out using two of the academic databases Scopus and web of Science (WoS).

A broad search strategy was also applied, which was carried out according to the criteria: ("maintenance management" OR "maintenance strategy" OR "maintenance planning" OR "maintenance optimization" OR "predictive maintenance" OR "preventive maintenance" OR "maintenance engineering") and ("SMEs" or "small and medium-sized enterprises" OR "small enterprises" OR "micro, SMALL AND MEDIUM-SIZED ENTERPRISES" OR "MSME" OR "MSMEs"

The search retrieved 174 investigations covering publications from 1992 to the beginning of 2025, which were selected to obtain a broad database that allows showing the publications made, the selection process was carried out through a process of filtering articles found in the Scopus and Web of Science databases, which were exported and merged using bibliometrix in R studio, which provided a bibliometric analysis that considers aspects such as publications by country, authors, institutions, number of citations.

To relate the keywords through network visualizations, identify co-authorship networks, patterns of international collaboration, VosViewer software was used, the combination of quantitative bibliometrics tools and network mapping allowed an understanding of the field of development.

3. Results

3.1 Annual Scientific Production

The analysis carried out on publication trends establishes that there is a growth between the years 2018 to 2022, which begins with a publication of 4 documents disclosed in 2018, reaching a peak of 35 articles in 2022, then a decrease in publications related to maintenance management in small and medium-sized companies is visualized.

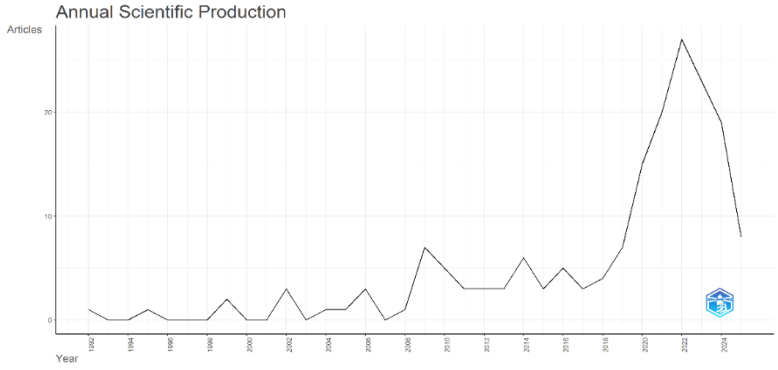

Fig. **1**. Annual scientific production

As can be seen in Figure 2 related to the growth of average citations per year, it is shown that there is a growth in the years 1999, 2011 and 2018, the most relevant since it coincides with the growth of the annual production of articles related to maintenance management in MSMEs.

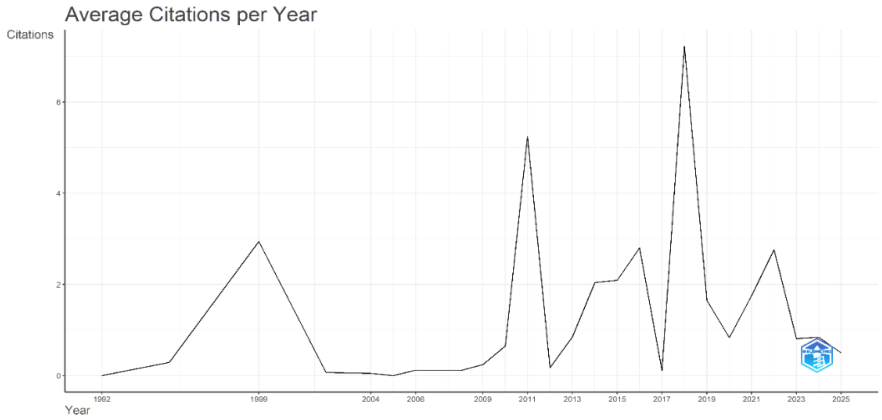

Fig. 2. Average citations per year

3.2 Leading countries in volume and impact of publications

The map of collaboration and academic connections, i.e. the geographical distribution of publications related to maintenance management according to Figure 3, reveals a greater concentration in the countries of India, the United States, Italy, with a lower concentration in the countries of the United Kingdom, Indonesia, Malaysia, Germany, Korea, Peru, Greece, Austria, China, Denmark, France, Portugal, South Africa, Australia, Canada, Colombia,

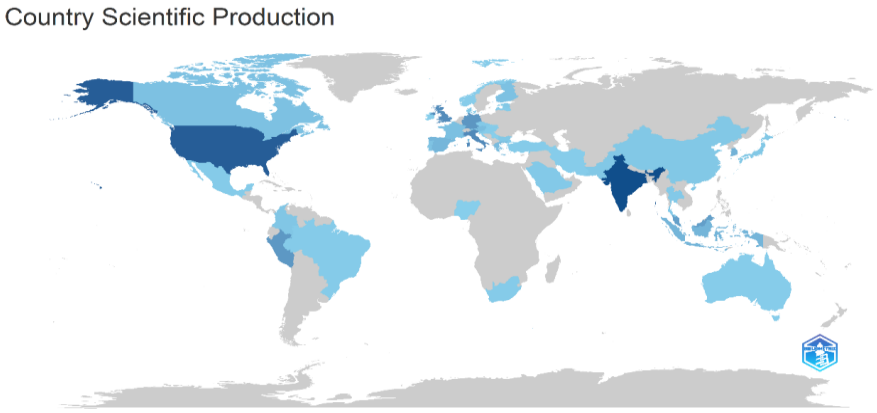

Fig 3. Geographical distribution of publications

Figure 4 shows a Sankey diagram of three fields that represents the relationship between the leading countries in the left column linked to maintenance, research topics, keywords central column that predominate search and in the right column institutional affiliations, this bibliometric analysis allows us to identify how international collaborations are articulated worldwide with the predominant research themes and institutions most influential academics in scientific production who act as nodes for the generation and dissemination of knowledge.

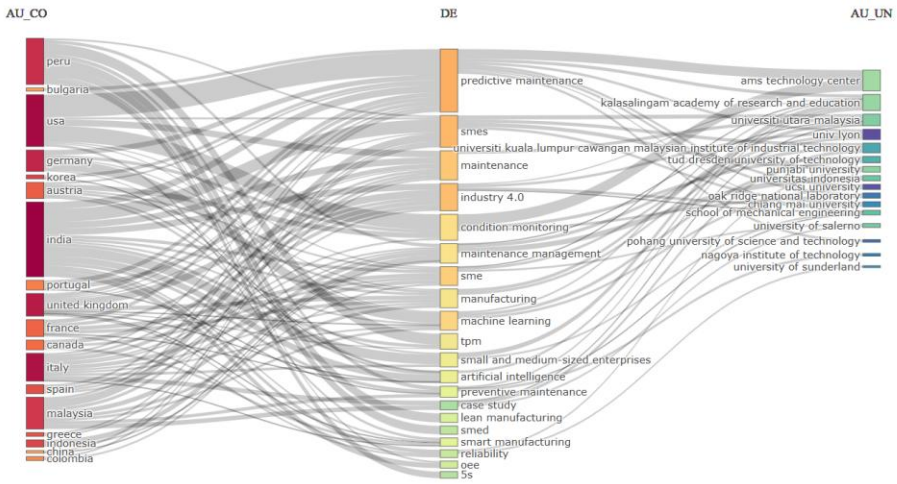

Fig 4. Geographical distribution of publications

In the initial column (AU_CO) there is a concentration of publications that come from India, the United States, Peru, Germany and Italy, which indicates that they have great contributions to this type of research related to maintenance, which plays an important role in manufacturing and production systems [6], as these countries have invested in strengthening scientific capacities and sustainable productivity strategies. India and Germany coincide with their significant push in national policies for the adoption of Industry 4.0, while the United States is a benchmark in technological development in industries[7].

In the central column (DE) you can identify keywords such as predictive maintenance, MSMEs, maintenance, Industry 4.0, monitoring, among others, which indicates the focus of the research topic and reflects the evolution of the discipline towards data-based maintenance models, the inclusion of TPM, lean manufacturing that allows reducing failures, optimize costs and improve the productivity of organizations [8].

The right column (AU_UN) shows the institutions that actively and frequently participate in research related to maintenance management in MSMEs, highlighting the AMS Technology Centre, the Kalasalingam Academy, the University of North Malaysia, other Research and Education institutions. The links between Asian, European and American universities suggest a balance between countries in the process of scientific consolidation and high-impact centers, which favors the transfer of knowledge, so there are several publications related to manufacturing problems due to the need to integrate manufacturing and sustainability [9].

3.3 Most cited countries, collaborative networks and influential affiliations.

By carrying out an analysis of citations by country, information is provided regarding the influence and global recognition of academic contributions in the field of maintenance management in small and medium-sized enterprises, contributing to the optimal performance of productive activities.

The United States maintains a leadership with 300 citations, followed by India with 234 citations, which reflects its great impact, other countries such as South Africa 83, Korea 62, Thailand 61, Australia 58, the United Kingdom 49, Germany 47, Italy 37 and Peru 32, also make their contribution with a smaller number of citations, which highlights that small countries can achieve a high impact with articles thanks to the results of academic research.

As well as in the distribution observed in Figure 5, it is possible to identify the predominance of North America and Asia, which indicates that they have a leading role and a central role in publications and the research agenda.

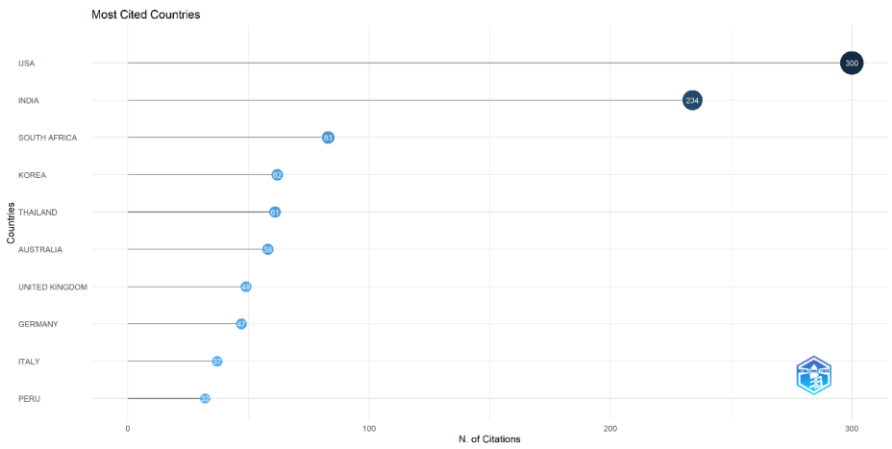

Fig 5. Total citations by country in research related to maintenance management

Figure 6 indicates an international network of scientific collaboration with modularity by country, with clear hubs such as India and the United Kingdom linked by links that suggest high intensity in collaboration, as well as around the United Kingdom orbiting Canada, Ireland, France, Denmark and Singapore, while Italy and Mexico appear as secondary bridges. The United States occupies an intermediate position, connected to the clusters of the United Kingdom and Germany, also more weakly with Asian nodes, Germany leads a European module with Greece, Finland and Hungary, with a more dense structure locally than globally.

At the extreme, countries such as South Africa–Nigeria and linear chains such as China–Pakistan–Bahrain–Austria–Czech Republic reveal regional collaborations with less intermediation. This pattern of "centers and peripheries," with hubs that shorten network distances, is consistent with the literature on centrality and self-organization in scientific networks.

Segmentation by communities suggests linguistic, historical, and science policy drivers: the Anglophone constellation (United Kingdom–USA–Canada–Ireland–Singapore) and the Eurocontinental constellation (Germany and neighbors) coexist with an Indo-European pole (India–Italy/Serbia) that acts as a hinge between regions.

The apparent high intermediation of the UK and India implies potential for gatekeeping and rapid dissemination of knowledge between modules, while the periphery could benefit from triadic co-authoring strategies and mobility programs to reduce dependence on single links.

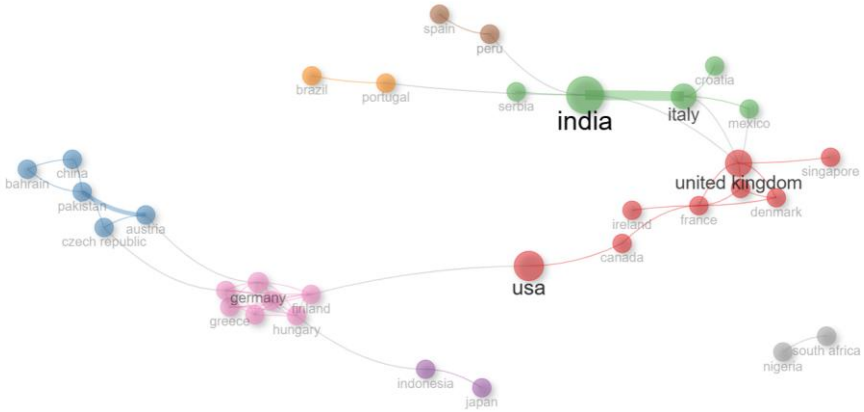

Fig 6. Scientific collaboration network

The frequency of contributions made by different institutions for the purposes of the study, according to figures 7 and 8 it is possible to indicate that the AMS Technology Center stands out with 19 articles which indicates its leadership in this type of publications, the Kalasalingam Academy follows with 18 articles, as well as the Universities of Punjabi, Malaysia, Salerno and Indonesia which are located in Asia and Europe make important contributions, it should be mentioned in a smaller number of publications and contributions to the School of Mechanical Engineering, Sungkyunkwan University, Tud Dresden University of Technology, Kuala Lumpur University which have an equal number of 5 contributions.

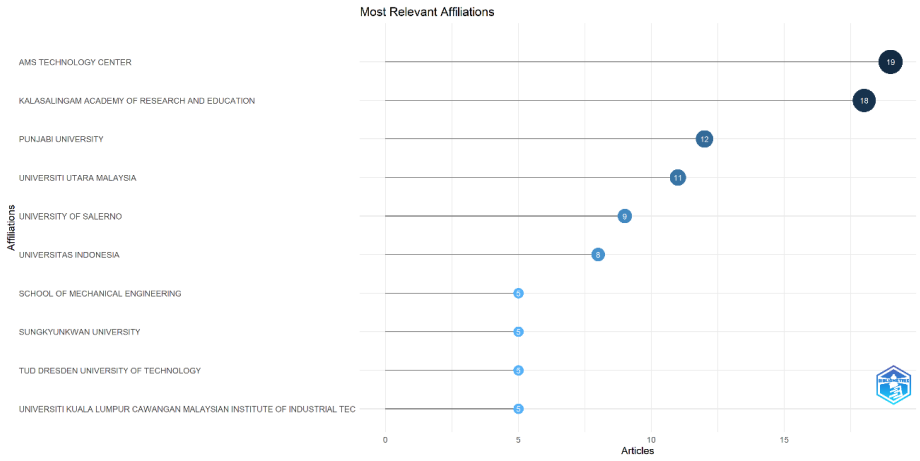

Fig 7. Most productive institutions by number of publications

Membership production over time

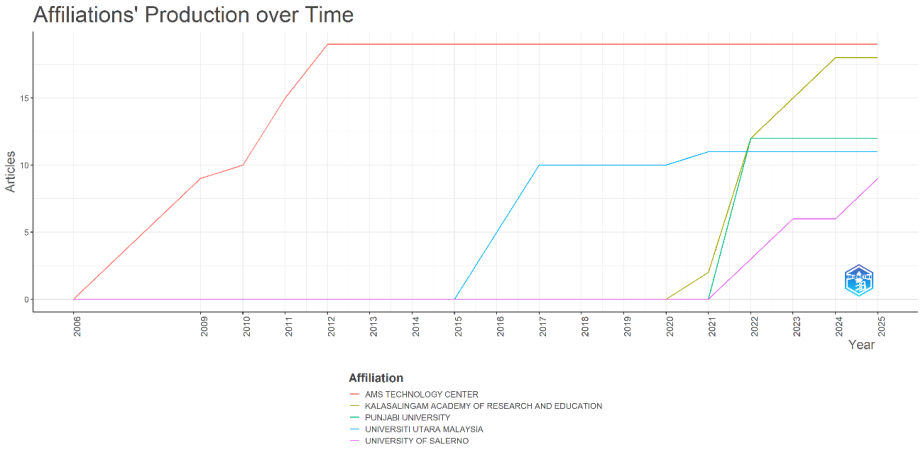

Fig 8. Membership production over time

The distribution of scientific publications according to the country of affiliation of the authors, considering publications from a single country (SCP) and publications with participation from multiple countries (MCP) Figure 9. India stands out as the country with the highest scientific production, followed by the United States, Italy, the United Kingdom, Indonesia in both modalities and Malaysia with publications from a single country, which indicates a high prominence of these countries in research related to maintenance, with a number of publications from a single country under the range of five are countries such as Germany, Korea, Greece, China, Denmark, Canada, Chad and Colombia, on the other hand under this same range of multi-country publications are the countries Peru, France and South Africa. it is possible to find countries such as Germany and Korea present publications without collaboration from other countries, and finally Austria, Portugal and Australia have an MCP participation.

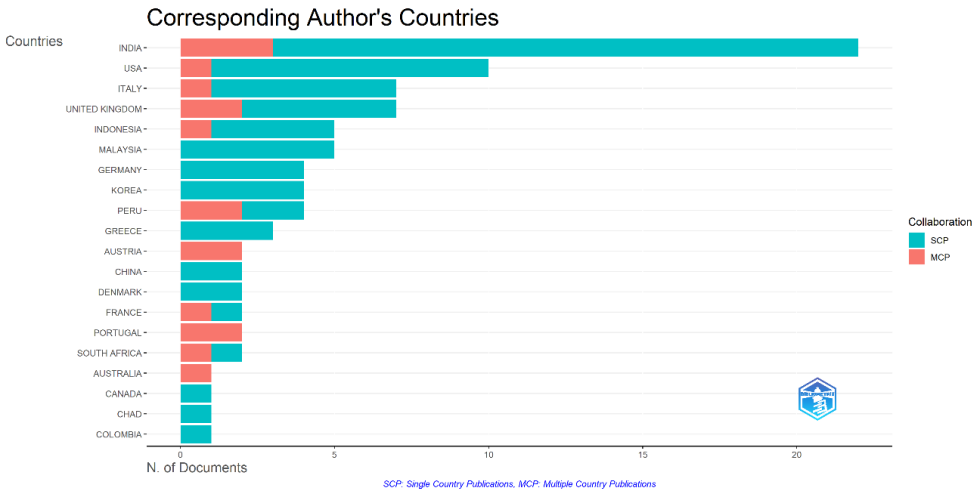

Fig 9. Distribution of authors by country, comparing publications from a single country and from several countries.

3.4 Most relevant authors and productivity analysis of the authors.

Performing an analysis of the authors' productivity provides information on the impact of research related to the topic of study, among the most relevant authors are Hashemian Hm. and Velmurugan K., with seven articles each, followed by Baglee D., Saravanasankar S., with 6 articles each, Ahuja Is., Di Pasquale V., Iannone R., Kiger Cj., Quiroz Flores Jc. Each author has published 4 articles respectively, according to figure 10.

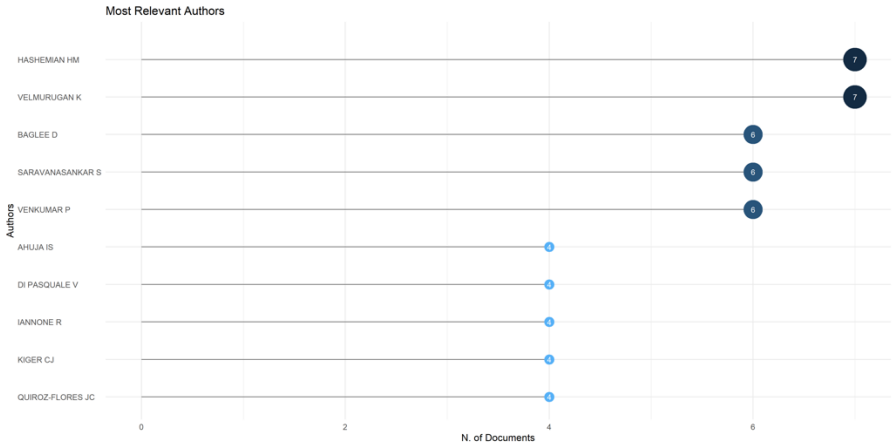

Fig 10. Productive authors in educational research related to maintenance.

The analysis of the productivity of the authors in the period from 2004 to 2024, in Figure 11, indicates an academic production of authors such as Baglee D., who has maintained a constant trajectory over time with publications spanning from 2004 to 2023, as well as authors such as Velmurugan K. and Saravanasankar S., which begin publications in 2021 and have an increase in articles in 2022, from which it can be seen that the variation in the production of articles over the years for other authors indicates an evolution in the research approach.

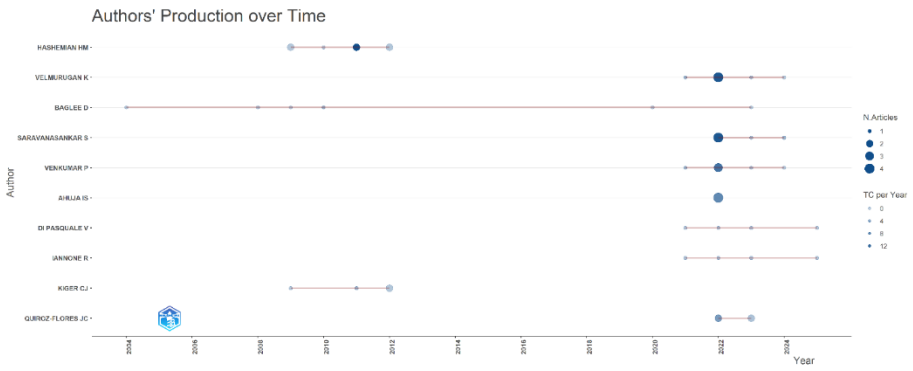

Fig 11. Author's productivity over time (2004-2024).

Figure 12 illustrates the productivity of authors through Lotka's Law, a fundamental principle in bibliometrics, which describes the frequency of publications and the contribution among researchers, on the x-axis the number of written documents is shown while on the y-axis it represents the percentage of authors. The trend shows an exponential decrease [10].

Most authors publish a single article and as the number of publications increases, the percentage of authors decreases drastically, it is the pattern mentioned by Lotka who postulated that scientific productivity follows a power-type distribution, where a few authors are responsible for most of the contributions [11], the evidence of a biased distribution in scientific production highlights the contribution of a small group of authors in the consolidation of maintenance management articles, so it is necessary to design support mechanisms that strengthen the work of authors and thus improve productivity.

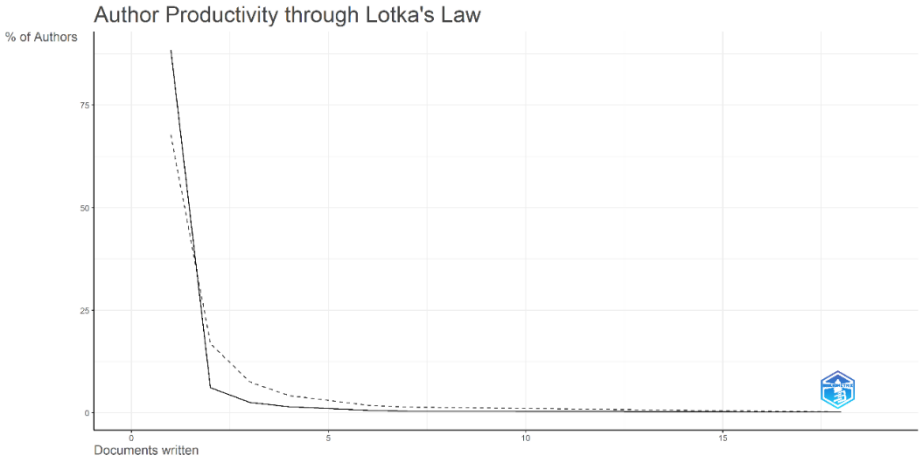

Fig 12. Distribution of the author's productivity according to Lotka's Law.

The three-field graph in Figure 13 presents a visualization of the relationship between authors, keywords and countries of publication influential in the field of maintenance, this diagram identifies the main authors in the first column, the most frequent keywords are shown in the middle column and the right column lists the main countries where the studies are published.

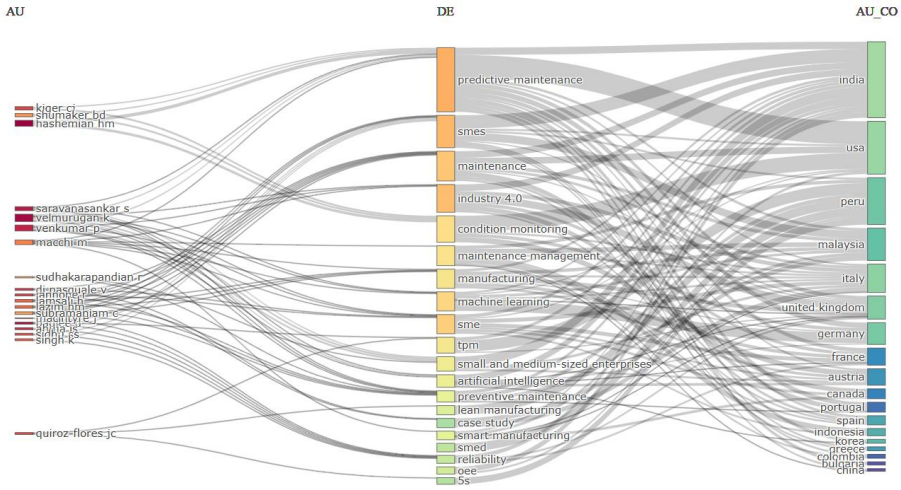

Fig 13. A three-field chart showing relationships between authors, keywords, and countries.

Authors such as Hashemian hm, Velmurugan K. and Venkumar P., occupy a prominent place due to the contributions made, as well as keywords such as predictive maintenance, MSMEs, maintenance management, monitoring, highlight the central research topics and the relationship with the countries of publication where India, the United States, Peru, among others stand out in greater and lesser scientific contribution.

This three-field connection presents the present relationship between authors, keywords and countries of publication with a research focus on preventive maintenance within MSMEs.

3.5 Analysis of the most relevant publication sources.

The analysis of publication sources indicates that certain journals have become a platform to disseminate research on maintenance management in MSMEs. Journals such as IFIP Advances Information and communication, Lecture notes in mechanical engineering, proceedings of the laccei international multi-conf, are among those with the highest number of publications, five each, followed by journals such as IFAC-Papersonline, journal of quality in maintenance engineering, lectures notes in networks and systems, computer science with 4 articles each, and to a lesser extent the international journal of advanced manufacturing, IOP, virtual eurolab. (Figure 14).

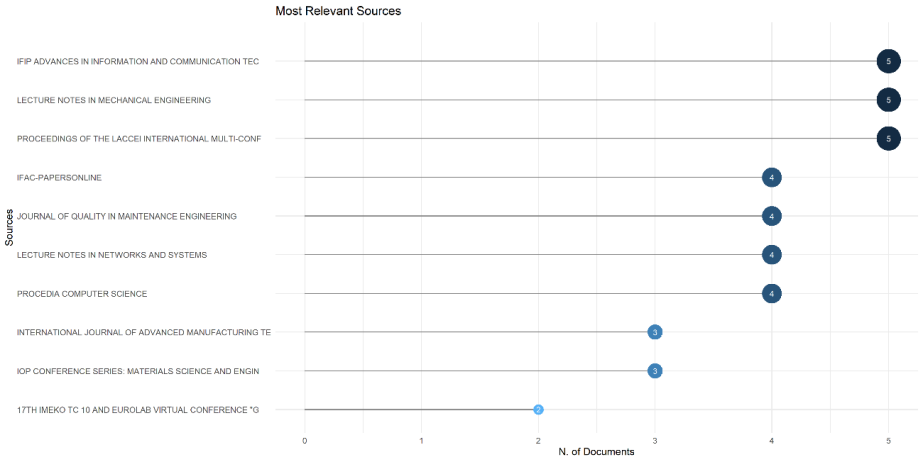

Fig 14. Most relevant publication sources.

Bradford's law states that as a hypothesis that most articles could be published by a few journals devoted to a specific topic [12], so in Figure 15 it is possible to identify that the journals mentioned as the most relevant sources of publication Figure 14, have the largest number of articles published related to the research topic that is maintenance management and MSMEs.

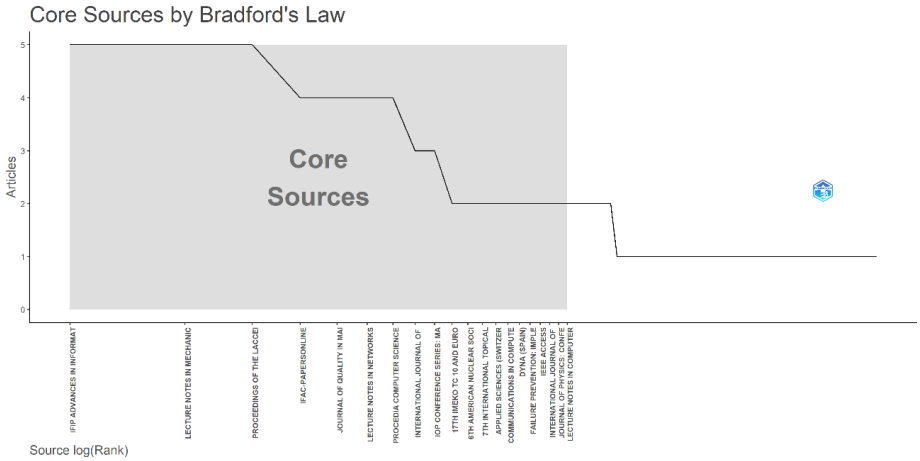

Fig 15. Main sources-Bradford's Law.

3.6 Authors' collaboration network.

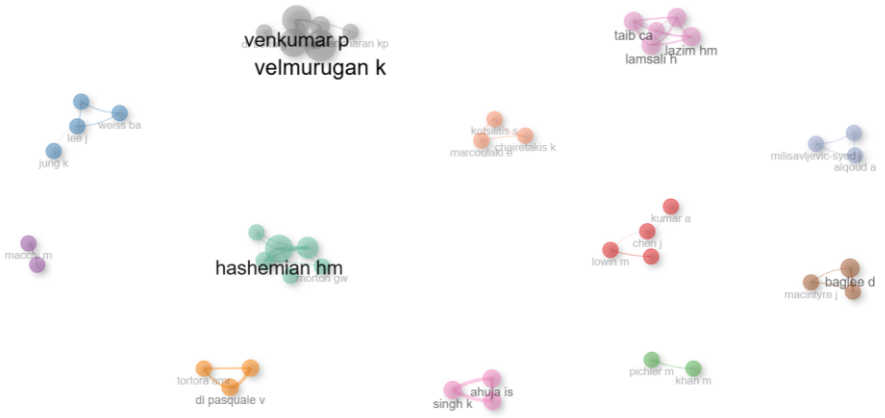

Fig 16. Authors' collaboration network.

Figure 16. shows a co-authorship map, i.e. a collaborative network of authors, which visualizes the scientific collaboration relationships between various authors, each node represents an author while the connections evidence joint publications highlighting collaborative groups and individual researchers, the network reveals different clusters, indicating various patterns of collaboration between researchers, the variation between the size of the names reflects the relevance and centrality within the network, the largest and most prominent cluster includes authors such as Hashemian Hm. and Velmurugan K., stand out as the main nodes with the highest number of collaborations, which indicates their role as articulators of productions focused on maintenance management.

The structure of the network evidences the existence of clusters or research communities, associated groups such as Venkumar P. and Velmurugan K, as well as smaller clusters that are linked to different authors, Taib Ca., Lazim Hm., Lamsali H., and Jung K., Lee J., Weiss Ba., who represent other collaborative units, and independently Macchi M.,

This closely connected group demonstrates strong internal collaboration , suggesting cohesive research efforts, likely characterized by frequent co-authorship and shared research interests.

3.7 Most cited articles.

The analysis of the ten most cited articles in the database indicates the most influential works related to maintenance management, in table 1 these articles are listed and metrics such as total citations, citations per year (TC per year) and normalized citation count (TC) are indicated. 2011), published in IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 60, NO. 1, with a total of 151 citations, and an annual citation rate of 13.80, this study describes the maintenance techniques based on the condition of the industrial process equipment, through passive techniques such as the use of sensors for data collection in the execution of the process and active techniques where test signals are introduced to measure its Answer [13].

The work of (Bamber Cj. 1999), carried out in the Quality in Maintenance Engineering, with 153 citations and an annual citation rate of 5.67, his study carried out an investigation regarding the factors that influence the implementation of Total Productive Maintenance TPM, taking data in a manufacturing SME and triangulating the results through documented review, obtaining a generic roadmap applicable to UK SMEs [14], as well as the study carried out by (Jain, A., 2014) and (Jain A, 2015), which focuses on the review of the literature related to the implementation of Total Productive Maintenance with the aim of obtaining an overview applicable to SMEs and large companies and thus improve productivity [15], [16].

Other contributions include (Sezer, E., 2018) and (Kiangala Ks., 2018) who focus their research on Industry 4.0, through basic and experimental methods that are low cost for small companies where data is obtained through temperature and vibration sensors including PLCs in order to optimize operations in SMEs [17] .

On the other hand (MADHAVAN M, 2022) and (CHEN J, 2021) conduct research on both systematic review of articles and data collection based on the characteristics of SMEs before and during the pandemic, by rethinking daily operations to achieve business objectives [18], [19].

As well as (Jin X, 2016), (Shin I, 2018), these studies describe how the monitoring of variables in companies based on diagnosis and prognosis, they allow the selection of the maintenance strategy [20], [21] .

Title	Article	DOI	Total Citations	TC per Year	Normalized TC
State-of-the-Art Predictive Maintenance Techniques	HASHEMIAN HM, 2011, IEEE TRANS INSTRUM MEAS	10.1109/TIM.2010.2047662	207	13,80	2,63
Factors affecting successful implementation of total productive maintenance: A UK manufacturing case study perspective	BAMBER CJ, 1999, J QUAL MAINT ENG	10.1108/13552519910282601	153	5,67	1,92
An Industry 4.0-enabled Low-Cost Predictive Maintenance Approach for SMEs: A Use Case Applied to a CNC Turning Centre	SEZER E, 2018, IEEE INT CONF ENG, TECHNOL INNOV, ICE/ITMC - PROC	10.1109/ICE.2018.8436307	94	11,75	1,63

Total productive maintenance (TPM) implementation practice: A literature review and directions	JAIN A, 2014, INT J LEAN SIX SIGMA	10.1108/IJLSS-06-2013-0032	92	7,67	3,76
Initiating predictive maintenance for a conveyor motor in a bottling plant using industry 4.0 concepts	KIANGALA KS, 2018, INT J ADV MANUF TECHNOL	10.1007/s00170-018-2093-8	81	10,13	1,40
The Precipitative Effects of Pandemic on Open Innovation of SMEs: A Scientometrics and Systematic Review of Industry 4.0 and Industry 5.0	MADHAVAN M, 2022, J OPEN INNOV: TECHNOL MARK COMPLEX	10.3390/joitmc8030152	61	15,25	5,53
Artificial intelligence-based human-centric decision support framework: an application to predictive maintenance in asset management under pandemic environments	CHEN J, 2021, ANN OPER RES	10.1007/s10479-021-04373-w	58	11,60	6,63
The present status and future growth of maintenance in US manufacturing: results from a pilot survey	JIN X, 2016, MANUF REV	10.1051/mfreview/2016005	57	5,70	2,04
A Framework for Prognostics and Health Management Applications toward Smart Manufacturing Systems	SHIN I, 2018, INT J PRECIS ENG MANUF GREEN TECHNOL	10.1007/s40684-018-0055-0	56	7,00	0,97
OEE enhancement in SMEs through mobile maintenance: a TPM concept	JAIN A, 2015, INT J QUAL RELIAB MANAGE	10.1108/IJQRM-05-2013-0088	55	5,00	2,39

3.8 Word cloud and co-occurrence keyword analysis.

The word cloud (figure 13) reveals a research agenda focused on preventive maintenance and application in small and medium-sized companies, including topics such as monitoring conditions, industry 4.0, machine learning, these concepts suggest preventive approaches based on diagnostic and decision-making tools in maintenance management, where the main objective is to anticipate failures, extend the useful life of equipment and optimize costs.

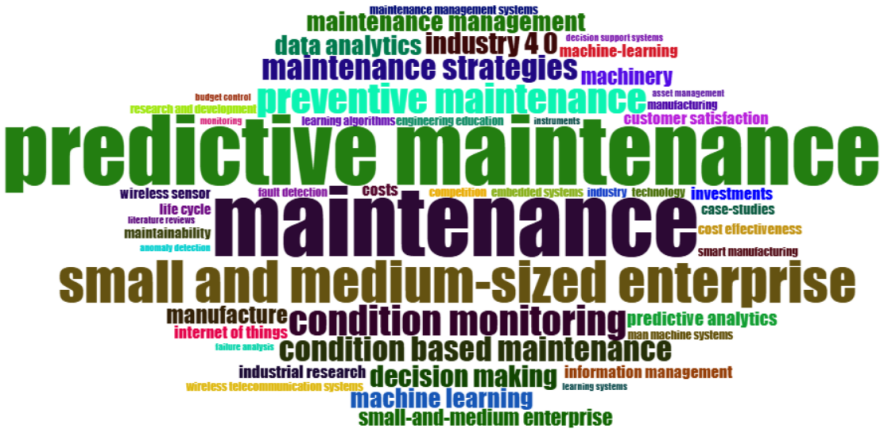

Fig 17. Word cloud.

As well as among the most frequent words observed in Figure 18, there are maintenance, predictive maintenance, small and medium-sized companies, followed by condition monitoring and preventive maintenance as reflected in Figure 17 and Figure 19 respectively, keywords in the bibliometric research carried out and that at the same time are linked since maintenance management within companies is necessary to improve productivity uy Their operability.

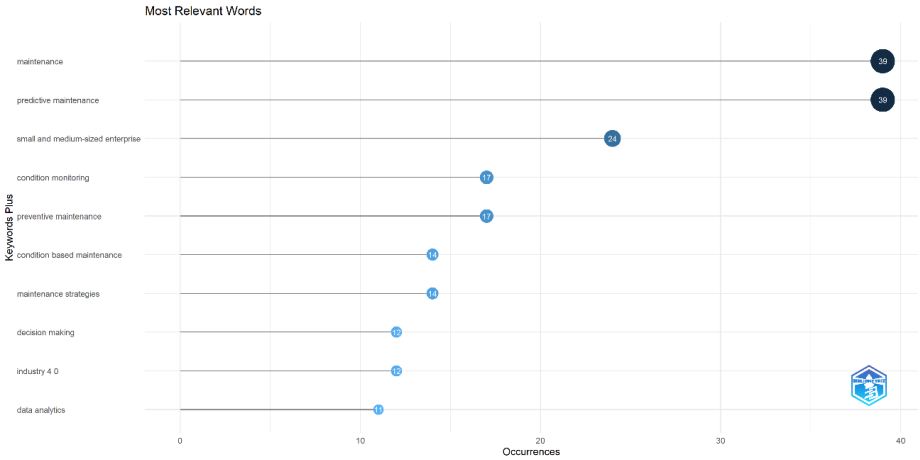

Fig 18. Most frequent words.

In the same way, the analysis of co-occurrence of keywords visualized in Figure 19 through network maps, provides important information regarding the main topics of the research that are related, it is possible to appreciate that there is a set of interconnected words around the main word such as "preventive maintenance". "medium and small enterprises" and at the same time these keywords are related to "monitoring conditions", "industry 4.0" which indicates a significant focus on maintenance management in MSMEs, which must be carried out through the monitoring of variables.

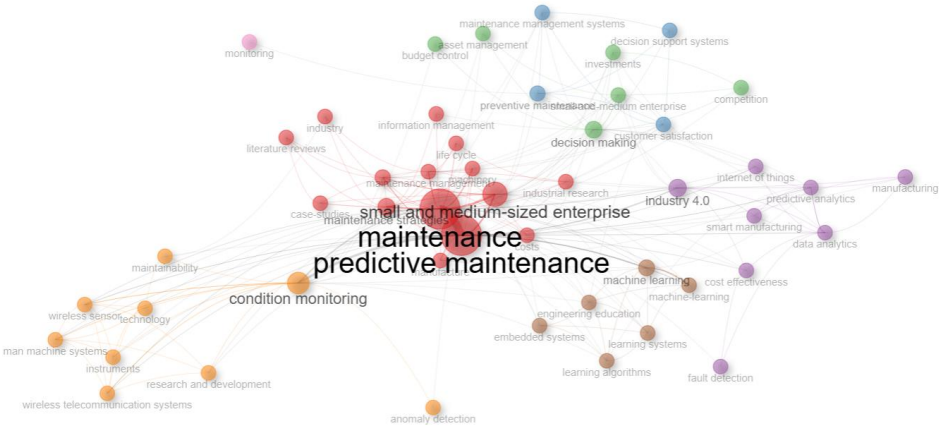

Fig 19. Keyword co-occurrence network map.

4. Conclusions and recommendations

The evolution of maintenance management, industry 4.0, predictive maintenance in MSMEs, is driving organizations towards the use of different maintenance tools [22], but they are still conditioned by economic barriers, capacities and data, different research shows that predictive maintenance requires a greater investment since it is necessary to maintain a database that allows predicting the mechanical failures that the equipment may present [6].

Maintenance management and Industry 4.0 fulfill the function of generating operational benefits, through the standardization of KPIs, document the variety of evaluation methods for technologies to monitor the operational conditions of the process [23], but the application in MSMEs is still limited, and is aggravated by the fact that the economic and comparative impacts compared to the traditional maintenance that are managed in companies are not specified.

The scientific production related to maintenance management in MSMEs, according to information collected in this research regarding bibliometric analysis, indicates that the largest number of articles were published in the countries of India, the United States and Italy, which is due to the performance and industrial competitiveness in the world. Thus, a sustained industrialization process implies an increase in productivity and this, in turn, in technological progress [24], industries such as the United States invests more than 200 billion dollars annually in the maintenance of equipment and industrial companies, despite the investment more than 60 billion dollars are lost due to inefficient maintenance [25].

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