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Original Research

Performance indicators and maintenance management: scientific mapping

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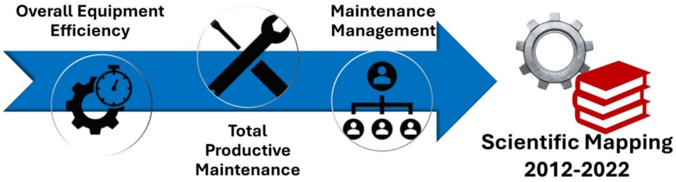

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Abstract: The versatility of Industrial Engineering means that professionals face productivity and efficiency challenges in different types and sizes of organizations. To deal with these challenges, practical tools for process optimization are needed, such as Overall Equipment Effectiveness (OEE) and Total Productive Maintenance (TPM), which are highly relevant due to their versatility. In this context, this work aims to research, organize, quantify, and discuss scientific articles in a theoretical review covering the topics of OEE and TPM, considering the large volume of scientific production on these topics. The research was conducted through a Systematic Literature Review that involved searching scientific databases and using the Bibliometrix software and its Biblioshiny extension to construct a scientific mapping. Additionally, a qualitative analysis of the article data was carried out to understand, discuss, and relate the data with scientific mapping, obtaining results on the main keywords, the leading countries with scientific production, the highlighted journals, the impact factor, and correlations between them.

Keywords: Overall equipment effectiveness, total productive maintenance, systematic literature review, Bibliometrix, industrial engineering, production performance.

Introduction

Intensified global competition requires companies to establish effective means to evaluate the performance of their production systems [1, 2]. Strategically managing production and operations to meet these criteria depends on production capabilities, involving decisions that seek high equipment efficiency and human resources [3]. In the industrial scenario, it is essential to ensure the high availability and reliability of equipment, promoting the company's performance through the competent use of its productive resources in an integrated system for evaluating global manufacturing performance and continuous improvements [2, 3]. Analyzing the efficiency of equipment requires the interpretation of several elements that can interfere with its performance, which highlights the importance of adopting indicators to evaluate the performance of the production system [3].

Various industrial sectors try to develop different methodologies to create real competitive advantages. However, Overall Equipment Effectiveness (OEE) has stood out as one of the best practices for evaluating the results of both Total Productive Maintenance (TPM) and Lean improvement activities [1], measuring equipment unavailability which directly affects the performance of the industrial process [2]. OEE, by the definition of Nakajima (1988) [4] is a metric within TPM which aims at improving productivity by reducing the six big losses (equipment failure, setup and adjustment, idling and minor stoppages, reduced speed, process defects and reduced yield), which are obstacles to achieve equipment effectiveness. In addition, other methodologies such as Kaizen, 5S, Kanban, and Six Sigma can also be used by industries that align with the Lean concept [5]. However, OEE is an essential indicator for managing and continuously improving production systems, helping identify losses, and reducing production costs [3].

The philosophy of total productive maintenance brought the notion that it is necessary to develop a more holistic view of the production system and, therefore, it is essential to establish a more comprehensive means of measuring the use of productive capacity [2, 3]. OEE, which measures the effective use of equipment capacity, was proposed as an indicator that fulfills this management control function [3]. Thus, OEE offers a direct approach to equipment improvements, which can be supported by techniques such as the Gantt Chart, Pareto Chart, Cause and Effect Analysis, Brainstorming, Control Chart, and Continuous Improvement [1, 2]. Therefore, OEE is an essential metric to ensure the success of TPM implementation programs [1, 2, 6].

A Systematic Literature Review (SLR) can comprehensively understand TPM and OEE, shedding light on their potential in this evolving landscape [1, 8, 9]. Recent studies also underscore the need for research that delves into the application of OEE in specific industries and diverse cultural and economic contexts [10, 11]. Furthermore, the applicability of OEE can be broadened, considering the escalating competitiveness in the global market [1]. Research can also focus on Predictive OEE to provide management and control with more detailed insights into production status [6].

Given the vast number of studies on OEE and TPM published in different contexts, there is a need to demonstrate the current scenario and directions for future research. Thus, this SLR aims to organize and discuss scientific articles, identifying new trends related to OEE and TPM. This research aims to inspire and motivate further exploration and application of these concepts in industrial engineering. In the following sections, the RSL method (2), the results obtained (3), the analysis of the articles (4), and the final considerations (5) will be presented, including suggestions for future research.

Experimental Section

This research is an SLR, a method outlined by [12] that involves several key steps: 1. Systematic Literature Review; 2. Literature Analysis; 3. Literature Synthesis; 4. Results. This method ensured a systematic and comprehensive literature review on OEE and TPM. The research is developed based on a robust and systematic method of searching, selecting, and analyzing data. The general steps of what was carried out are summarized in Figure 1 and detailed in the following topics. This method ensures the reliability and validity of our findings, providing a solid foundation for our research.

The databases selected for the research were the CAPES Journal Portal, Science Direct, Scopus, and Web of Science. Due to the international scope of the search, keywords in English were used, including "OEE and TPM"; "Overall Equipment Effectiveness and Total Productive Maintenance"; "Overall Equipment Effectiveness and Maintenance Management"; and, finally, "OEE and Maintenance Management". Considering the logic of search terms, the "AND" operator was used.

Concerning the filters used in the search results, publications between 2012 and 2022 were first considered to prioritize recent studies about the execution of this research. The type of document was also a selection criterion, prioritizing the type "articles" in the CAPES journal database, "conference article" and "review article" in the Science Direct and Scopus databases, and, finally, "conference article" and "article" in the Web of Science database. The type of subject was also used as a selection criterion, targeting the articles most related to the

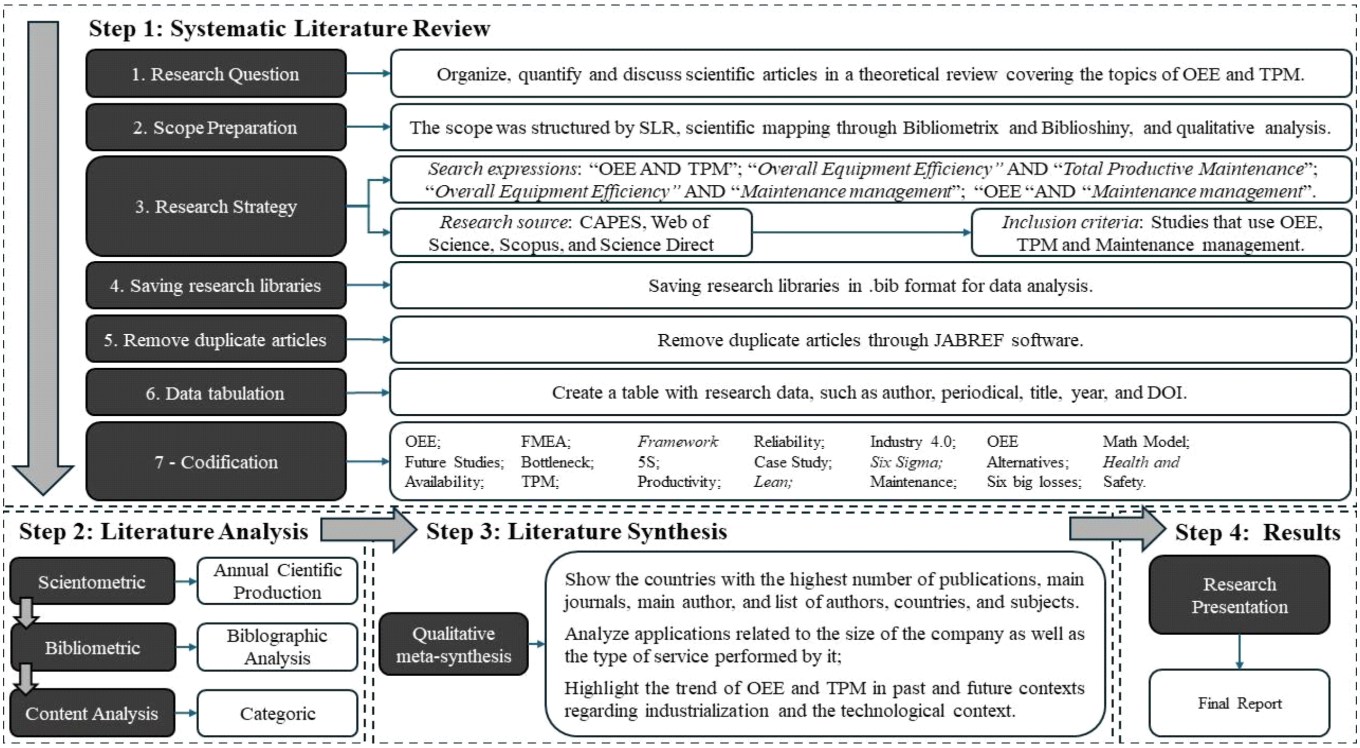

Figure 1. Summary of the methodological steps developed in the research.

objective of this research (due to the vast list, it is presented as a result in Table 1 of item 3.1). The last selection criterion considered the English language as a database preference.

After searching the databases with the respective strings and filters, the grouped data from each search was stored in digital library format files (.bib extension) and later arranged in the Mendeley Software, aiming to remove duplicate articles. Using the same software, a table was generated in tabular format (Microsoft Excel), containing data on authors, titles, years of publication, periodicals, types of documents, and Digital Object Identifier (DOI). A "filter" was used in table columns for a textual search in the title of the articles with the following keywords: "OEE", "Overall", "TPM", "Total Productive Maintenance", and "Maintenance Management". Thus, the articles were separated into three colors: red for reference outside the research topic, yellow for those that required additional reading for selection or exclusion, and green for articles that were by the objective of the work.

A list of articles was created using the selected references, highlighting their characteristics, methodology, objectives, and results. After this process, the articles were grouped according to the main subjects. After completing the registration and grouping of the recurring themes, the research was directed to the scientific mapping of the articles resulting from the SLR.

Scientific mapping sought the characteristics of a set of research published through journal articles (or other means), aiming to identify the number, evolution (in a timeline on the topic), the principal authors, and citations of the publications in question. As previously mentioned, Bibliometrix with the Biblioshiny extension was used for this study. Where Bibliometrix, according to [13], provides a set of tools for quantitative research in bibliometrics and scientometrics, and Biblioshiny, according to [14], is an extension powered by Bibliometrix, but with a web-based graphical interface.

Regarding the file format used for scientific mapping, searches in the Scopus and Web of Science databases were redone to save the results in the .ris extension. This resulted in some articles 0.49% greater than that of the initial search, or 615 articles. Another essential factor that must be highlighted is that the defined search bases were not decided randomly, but rather, due to the limitations of Bibliometrix data analysis. In fact, these databases present the most significant accumulation of articles and the quality of publications that undergo peer review. Still on the extension of biblioshiny, the following menus were to obtain the analyses: Wordcloud – Author's Keywords; Author's – Country Scientific Production; Sources – Most Relevant Sources; Source Impact – Total Citation; Most Relevant Authors – Number of Documents; Author Impact – Total of Citations; Word Dynamics – Author's Keywords; Overview – Three-Field Plot (Countries – Keywords – Authors).

In qualitative analysis, in the case of results analysis, a comparative evaluation of qualitatively defined subjects is carried out with the cloud of keywords generated through the Bibliometrix (quantitative method). Another essential analysis developed was the proposal for future studies in the selected articles. In this way, the results were obtained considering the steps described, and the analyses and discussions set out in the following topic were generated.

After selecting through filters by title and reading article summaries, the final number of 73 articles was obtained. On these, a grouping of the main subjects covered in the articles was made, these being Framework, OEE, Alternatives for OEE, Six Big Losses, TPM, Case Study, FMEA, Bottleneck, Availability, Maintenance, Productivity, Industry 4.0, Lean, Reliability, Six Sigma, Ergonomics, Health and Safety, Mathematical Model, and 5S.

Results and Discussion

The results of this research, which are presented in a structured manner according to the SLR methodology developed, the scientific mapping, the quantitative results generated, and the qualitative analysis, are of paramount importance to the field of industrial engineering, and maintenance management. The correlation of selected articles, approaches between the SLR results and the generated mapping, and the causalities of the results found from the analyses carried out all contribute to developing and deepening new studies in these areas.

Literature analysis

Table 1 provides a comprehensive summary of the initial stages of the RBS, including the results obtained in each database based on the application of specific filters. This thorough literature analysis process ensures that all relevant data is considered, providing a solid foundation for the research.

After thoroughly searching the databases using the respective strings and filters, the collected data was organized in the Mendeley software to remove duplicate articles, resulting in a dataset of 612 documents. A table was also generated (in Microsoft Excel) containing data on authors, titles, years of publication, periodicals, types of documents, and DOI. This data collection process ensures the accuracy and reliability of the research findings.

A list of articles was created using the selected references (identified in green), highlighting their characteristics, methodology, objectives, and results. After this process, the articles were grouped according to the main subjects covered, resulting in the 19 main themes of the file, previously described in the topic regarding methodology. The complete grouping table is available in Supplementary Material as Table S1.

Results of Scientific Mapping

The results obtained through bibliometrics considered for this research permeate the following aspects: the main keywords; the main countries with scientific production on the subject; the main periodicals; the local impact factor (articles,

Table 1. Summary of the results of the first stages carried out by SLR.

Keywords	Filter 1	Filter 2	Filter 3	Total
CAPES (Total: 190 articles)				
"OEE" E "TPM"	Article	Engineering; Science & Technology; Technology; Maintenance; Overall Equipment Effectiveness; Total Productive Maintenance; OEE; TPM; Manufacturing; Maintenance Management; Productivity; Engineering, Industrial; Engineering, Manufacturing; Social Sciences; Downtime; Lean Manufacturing; Management; Business & Economics; Availability	English	91
"Overall Equipment Effectiveness" AND "Total Productive Maintenance"	Article	Engineering; Science & Technology; Total Productive Maintenance; Technology; Maintenance; Overall Equipment Effectiveness; Productivity; Maintenance Management; Efficiency; Engineering, Industrial; Manufacturing; Management; Engineering, Manufacturing; Business & Economics; Availability; Lean Manufacturing; Tpm; Case Studies	English	44
"Overall Equipment Effectiveness" AND "Maintenance Management"	Article	Maintenance Management; Engineering; Science & Technology; Maintenance; Productivity; Overall Equipment Effectiveness; Technology; Effectiveness; Total Productive Maintenance; Overall Equipment Effectiveness; Cost Analysis; Analysis; Decision Analysis; Business & Economics; Decision-Making; Management; Decision Making	English	8
"OEE" AND "Maintenance Management"	Article	Maintenance Management; Productivity; Manufacturing; Engineering; Maintenance; Preventive Maintenance; Management; Effectiveness; Overall Equipment Effectiveness; Total Productive Maintenance; Business & Economics; Breakdowns; Engineering, Industrial	English	47
Science Direct (Total: 265 articles)				
"OEE" AND "TPM"	Conference Article; Article; Review Article	Engineering; Decision Sciences; Economics, Econometrics and Finance; Business, Management and Accounting	English	147
"OEE" AND "Maintenance Management"	Conference Article; Article; Review Article	Engineering; Decision Sciences; Economics, Econometrics and Finance; Business; Management and Accounting	English	66
"Overall Equipment Effectiveness" AND "Total Productive Maintenance"	Conference Article; Article; Review Article	Engineering; Decision Sciences.	English	32
"Overall Equipment Effectiveness " AND "Maintenance Management"	Conference Article; Article; Review Article	Engineering; Decision Sciences; Business; Management and Accounting; Economics, Econometrics and Finance	English	20
Scopus (Total: 839 articles)				
"OEE" AND "TPM"	Conference Article; Article; Review Article	Engineering; Business, Management and Accounting; Decision Sciences	English	351
"OEE" AND "Maintenance Management"	Conference Article; Article; Review Article	Engineering; Business, Management and Accounting; Economics, Econometrics and Finance	English	264
"Overall Equipment Effectiveness" AND "Total Productive Maintenance"	Conference Article; Article; Review Article	Engineering; Business, Management and Accounting; Economics, Econometrics and Finance.	English	164
"Overall Equipment Effectiveness" AND "Maintenance Management"	Conference Article; Article; Review Article	Engineering; Business, Management and Accounting; Decision Sciences	English	60
Web of Science (Total: 67 articles)				
"OEE" AND "TPM"	Conference Article; Article; Review Article	Engineering Industrial; Engineering Manufacturing; Operations Research Management Science; Engineering Mechanical.	English	52
"Overall Equipment Effectiveness" AND "Total Productive Maintenance"	Conference Article; Article; Review Article	Engineering Manufacturing; Engineering Industrial; Engineering Mechanical; Management; Mechanics; Operations Research Management; Science	English	9
"OEE" AND "Maintenance Management"	Conference Article; Article; Review Article	Engineering Industrial; Engineering Multidisciplinary Engineering Mechanical; Management	English	4
"Overall Equipment Effectiveness" AND "Maintenance Management"	Conference Article; Article; Review Article	Engineering Mechanical; Management	English	2

journals, and authors); the accumulated frequency of keyword occurrence over time; and the relationships between keywords, countries, and authors.

In the scientific mapping phase, a quantitative analysis was developed of the most repeated subjects in articles (Figure 2), resulting in the word cloud generated by Biblioshiny. This contains the 30 words that appeared most in the selected articles.

Figure 2. Keyword cloud obtained through Biblioshiny.

With the data obtained, it was possible to verify the ten countries with the most significant scientific production on the subject, that is, the most significant number of articles published, namely India with 101 articles, Indonesia with 29, Italy with 29, Malaysia 28, Poland with 27, Brazil with 24, Sweden with 24, Spain with 21, the United Kingdom with 21 and Portugal with 16. In Figure 3, it is possible to see the scientific production of articles on the research topics.

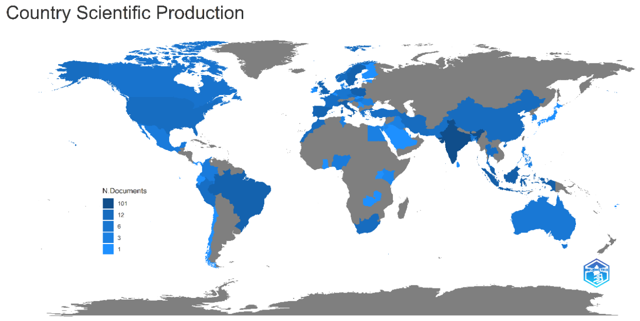

Figure 3. Countries with occurrence of publications on the topic.

Regarding journals, the 10 with the highest number of articles were the Journal of Quality in Maintenance Engineering with 38 articles, Proceedings of the International Conference on Industrial Engineering and Operations Management with 29, International Journal of Productivity and Quality Management with 24, International Journal of Production Research with 19, International Journal of Productivity and Performance Management with 16, IOP Conference Series: Materials Science and Engineering with 16, Procedia Manufacturing with 14, Applied Sciences (Switzerland) with 11, International Journal Of Quality And Reliability Management with 11 and Journal Of Manufacturing Technology Management with 11 articles. Figure 4 presents the graph with the number of articles in the ten journals with the most articles within the research.

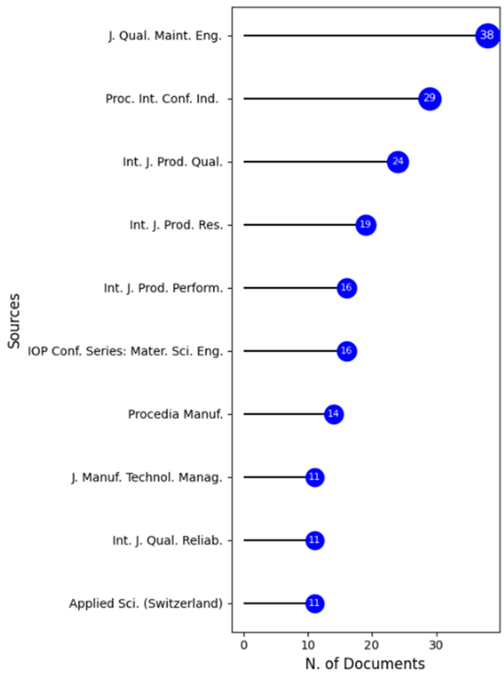

Figure 4. Graph of number of articles in the ten journals with the highest occurrence of articles.

When evaluating the impact factor, the total number of citations of the journals was considered. The ten most cited are the Journal of Quality in Maintenance Engineering with 573 citations, the International Journal of Production Research with 479, the International Journal of Productivity and Performance Management with 296, the International Journal Of Quality And Reliability Management with 264, Journal Of Manufacturing Technology Management with 264, Procedia Manufacturing with 192, Benchmarking with 182, International Journal of Lean Six Sigma with 166, International Journal Of Quality And Management with 152 and Journal of Cleaner Production with 135 citations. Figure 5 shows the journals with the highest number of citations.

The study researched the Scopus percentile factors of the same journals as a comparison criterion. Journal of Quality in Maintenance Engineering presents a Scopus citation percentile of 69%; International Journal of Production Research that does not present a Scopus percentile of citations; International Journal of Productivity and Performance Management which does not yet have a Scopus percentile; International Journal Of Quality And Reliability Management which presents a Scopus citation percentile of 77%; Journal Of Manufacturing Technology Management which presents a Scopus citation percentile of 89%; Procedia Manufacturing periodical that was discontinued in 2022; International Journal of Lean Six Sigma which has a Scopus citation percentile of 92%; International Journal Of Quality And Management which presents a Scopus percentile of citations of 77%; the Journal of Cleaner

Production which presents a 90% percentile; the International Journal of Production Research which has a 99% percentile and finally the International Journal of Productivity and Performance Management with an 83% percentile. In short, the cited journals present a reliable percentile, except for Procedia Manufacturing, which was discontinued. However, when active, it had a JCR (Journal Citation Reports) impact factor of 1.74 (2020-2021).

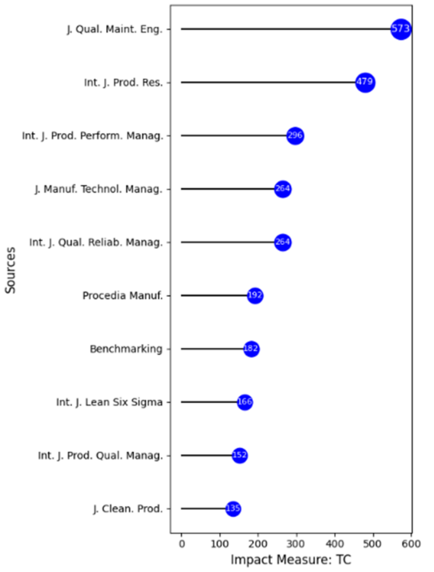

Figure 5. Graph the number of articles in the ten journals with the most citations.

Still, concerning quantitative analyses, the ten authors with the most articles published in the research are Francisco Silva, with 13 articles ; Anders Skoogh, with 11 articles; Inderpreet Singh Ahuja, with ten articles; Panagiotis Tsarouhas, with nine articles; Jon Bokrantz with seven articles; Luis Pinto Ferreira with seven articles; Jose Arturo Garza-Reyes with seven articles; Muhammad Ali Khan with seven articles; Nallusamy with seven articles and Harwinder Singh with seven articles. Among the three most cited authors, Francisco Silva is affiliated with an educational institution in Portugal; Anders Skoogh is affiliated with an educational institution in Sweden; and Indrepreet Singh Ahuja is affiliated with educational institutions in India. Figure 6 shows the graph of the ten authors with the most articles published within the research.

Concerning the local impact factor, based on the total number of citations of the authors, the most cited authors are Diego Galar with 256 citations; Uday Kumar with 255 citations, Aditya Parida with 255 citations; Christer Stenström with 255 citations; Anders Skoogh with 170 citations; Jeongcheol Lee with 159 citations; Harwinder Singh with 151 citations; Luis Berges with 143 citations, Francisco Silva with 139 citations and Saumyaranjan Sahoo with 138 citations. Still, in this aspect, it is essential to highlight that the authors Francisco Silva and Anders Skoogh also appear on the list of the most relevant authors in terms of some articles, in addition to appearing as most relevant in some citations (Figure 7).

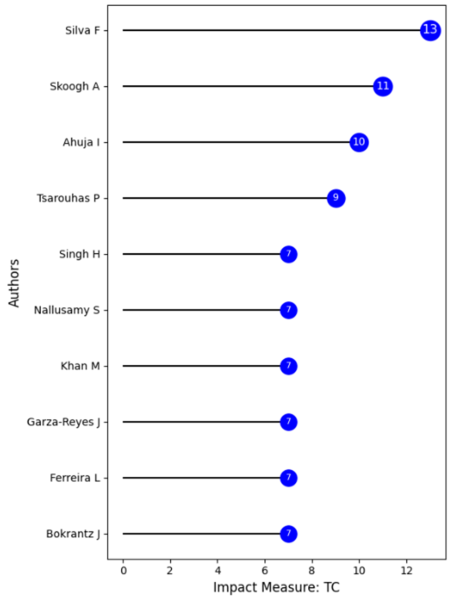

Figure 6. Authors with the highest number of articles published within the research.

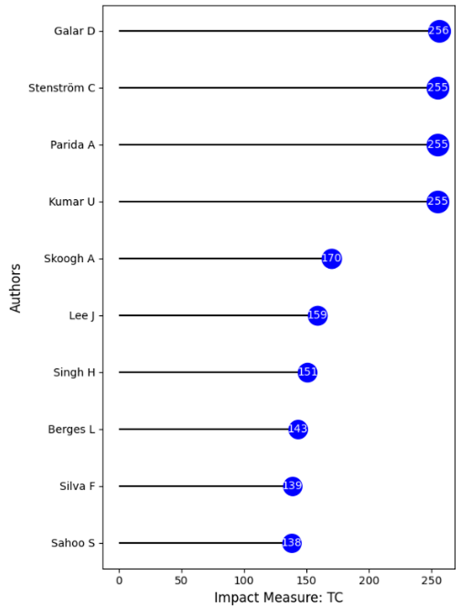

Figure 7. Graph with the authors with the most citations in local search.

To the keywords defined by the authors in accumulated occurrences over time, that is, from 2012 to 2023, it is possible to observe the occurrence of the terms (in English): Availability, Industry 4.0, Lean Manufacturing, Maintenance, OEE and Global Equipment Effectiveness (which are synonyms), Performance Measurement, TPM and Total Productive Maintenance (synonyms) and productivity.

The graph shown in Figure 8 shows the growth in the occurrence of all keywords. One that stands out among the subjects related to research is the term industry 4.0, which showed a significant growth in publications, going from 2 (in 2018) to 27 publications (in 2022). This demonstrates the growth in the relationship between Industry 4.0 and issues related to OEE and TPM.

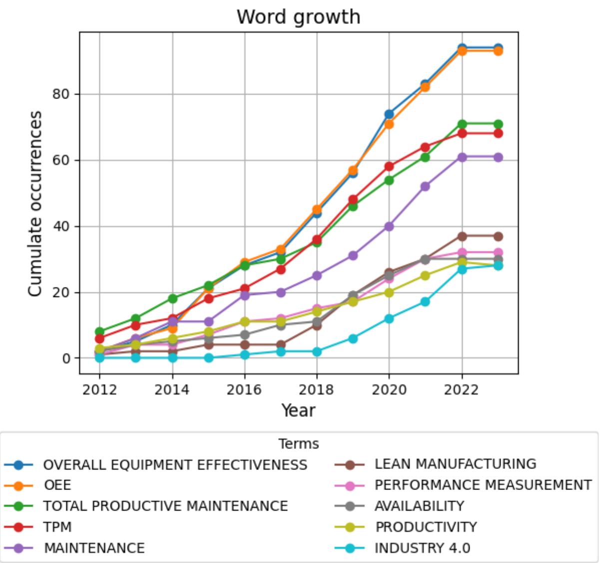

Figure 8. Accumulated occurrence of keywords as a function of time.

Qualitative Analysis of Results

Firstly, relating the subjects defined when reading the articles and the subjects generated by the word cloud (quantitative result), it is possible to notice that some words appear in both, such as OEE, TPM, availability, maintenance, productivity, industry 4.0, Lean Manufacturing, reliability, Six Sigma, and 5S. Other words do not appear in the cloud, such as Framework and case study, as the word cloud does not categorize the type of article, as was done in the qualitative analysis. Another term not included in the word cloud is "Alternatives for OEE," as it is a grouping of several articles that present other ways of calculating productivity without necessarily being the Overall Equipment Effectiveness. Finally, other terms do not appear in the cloud because they are subjects mentioned in a few scientific mapping articles: six significant losses, ergonomics, health and safety, and mathematical model.

The following analyses were developed from the qualitative analysis of the articles. The first refers to the identification that out of 25 theoretical review studies, 19 deal with issues related to OEE, and 12 deal with issues related to TPM. About occurrences, 8 articles deal with both subjects: OEE and TPM.

Regarding theoretical reviews, the present study highlights the article written by Lakho et al. [8], whose one of co-authors is Khan, M.A., who is among the ten authors with the most published articles, data obtained in the quantitative analysis. The authors' theoretical review discusses the implementation of OEE in maintenance management. The research seeks in the literature to present the applications of the leading lean tools, that is, the general effectiveness of the equipment in industrial sectors along with its effectiveness, impacts, and results after implementation, in addition to discussing OEE applications in various types of industries in detail.

A second finding concerning qualitative analysis refers to articles focused on case studies. There are 40 studies; among them, 23 articles have subjects related to OEE, and 27 articles have subjects related to TPM. An intersection of 13 articles has subjects related to OEE and TPM.

Concerning case studies, the case study carried out by Nallusamy S. [15] stands out, as it deals with a study of the effectiveness of implementing an independent maintenance system on CNC machines in a small mechanical workshop to improve OEE. It relied on the help of Total Productive

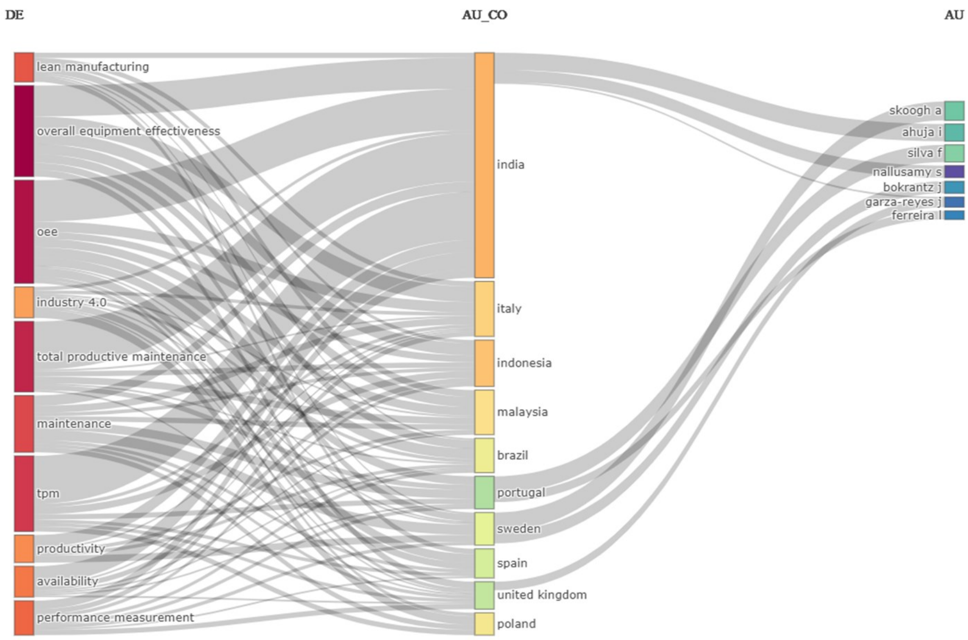

Figure 9. Three-field graph relating keywords, countries, and authors.

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Maintenance techniques, such as 5S, preventive maintenance, and cleaning, using a systematic analysis through surveys, research discussions, documentation review, sequential records, and direct observations. The work seeks to address availability, performance, and quality, which are indicators used to calculate the OEE of a machine. The results obtained at the end of the study show that OEE improved by 5% in one piece of equipment and 7% in another.

Also noteworthy is the case study developed by Sukma et al. [16], carried out in the city of Jakarta, Indonesia, at the Government Hospital, which offers cancer treatment services through different types of available equipment, one of which is the object of the study (Linear et al. - Synergy Platform). The study showed a low effectiveness of OEE. The research aimed to use TPM techniques as a parameter and FMEA (Failure Mode and Effect Analysis). As a result, it was possible to verify that the factors that most influenced the low OEE value in the machine were breakdowns with a percentage of 76.29% and loss of setup of 9.59%. To alleviate these problems, stocks of spare parts were built, and the consistent implementation of the TPM pillars improved OEE results.

Finally, the case study developed by Tsarouhas et al. [17] is considered relevant within the set of research analyzed, with the author being among the ten authors with the most articles published in local research. The research refers to the relationship between factory management and the operation of a traditional Italian cheese line through the analysis of data on failures and repairs in the line for a consecutive period of 26 months. Furthermore, the study calculated the availability, performance, and quality index factors, making it possible to note that the line's performance is 76.47%, below the target of 85%. The study also shows that the leading causes are speed losses that impact performance and stop that affect availability, leaving the line with 88.41% availability. The article concludes that the company needs a new maintenance strategy soon.

Given the above, in the qualitative analysis, this article aims to bring articles on the topic of OEE and TPM related to Industry 4.0, which refers to the fourth industrial revolution [18]. According to Bigliadi et al. [19], Industry 4.0 aims to achieve higher operational efficiency along with increased productivity and automation. It is triggered by a specific technology: the Internet of Things (IoT), and it is sustained by other pillars such as Machine-to-Machine communication, Big Data, Cyber-Physical Systems, Digital Twins, Augmented Reality, Additive Manufacturing, Cybersecurity, and Cloud Computing. Zhou et al. [20] highlight the pioneering countries in the fourth industrial revolution as the USA, Germany, Japan, South Korea, and China—each of which has a distinct vision of Industry 4.0.

Among the articles selected in the qualitative analysis, only four are directed to the Industry 4.0 theme; returning to the quantitative analysis (total of 615 articles), there are only 27 articles. The case study developed by [7], about four industries located in southern Brazil, aims to examine the integration of Industry 4.0 and TPM technologies in large manufacturing companies. As a result, it is exposed that integrating Industry 4.0 with TPM tools results in benefits and some barriers to absolute advantage, compatibility, complexity, testability, and observability. The author also highlights that identifying the aspects that can restrict the successful digitalization of TPM can help companies promote countermeasures to encourage innovation adoption.

Conclusions

Quantitative data analysis revealed that most articles from the top five countries that have published the most studies on OEE and TPM - India, Italy, Indonesia, Malaysia, and Brazil - originate from industrialized nations that have yet to adopt the industry culture fully. 4.0, unlike pioneers in this field, such as Germany, Japan, South Korea, China, and the United States. Furthermore, this analysis highlighted the scarcity of studies aimed at integrating TPM and OEE tools with Industry 4.0, especially in the most advanced countries on this topic.

For the qualitative analysis, the case studies demonstrated the versatility of the topic, revealing the applicability of TPM and OEE tools in industries of different segments and sizes. This approach allowed the organization and discussion of relevant scientific articles on OEE and TPM, in addition to highlighting new trends related to this topic.

The comprehensive review carried out in this study on Overall Equipment Effectiveness and Total Productive Maintenance highlighted the importance and applicability of these methodologies within the scope of Industrial Engineering. This systematic review identified the main trends and gaps in the literature, offering a detailed overview of the

main topics and research methods used. The results highlighted the relevance of OEE and TPM in improving the efficiency and effectiveness of production processes, as they are widely used in various industrial sectors. The analysis of the articles highlighted the importance of a holistic approach to maintenance management and the need to integrate different continuous improvement methodologies, such as Kaizen, 5S, Kanban, and Six Sigma, with OEE and TPM.

Furthermore, the research highlighted the growing importance of Industry 4.0 and the need to adapt OEE and TPM practices to the new technological context. Integrating advanced technologies like IoT, Big Data, and Artificial Intelligence represents a significant opportunity to improve maintenance and production management practices.

However, some limitations were identified, such as the restriction to two databases and the need for additional empirical studies to validate the hypotheses raised. Future research should explore the application of OEE and TPM in different cultural and economic contexts and their integration with other lean manufacturing philosophies. Concerning the 72 articles chosen for the qualitative analysis, 33 presented suggestions for future studies. Table 2 summarizes academic and industrial needs for new studies. These future research options aim to deepen knowledge about OEE and TPM and explore new approaches to maximizing the effectiveness of maintenance and production management practices.

Table 2. Future study suggestions.

Main topic	Description	Objective of future research
OEE and TPM in specific industries	Investigate the OEE and TPM application in specific sectors, such as automotive, pharmaceutical, and electronics.	Evaluate the effectiveness and adaptability of OEE and TPM practices in different industrial contexts.
Integration with Industry 4.0	Explore the integration between Industry 4.0 technologies with OEE and TPM.	Develop frameworks integrating IoT, Big Data, and AI with OEE and TPM for continuous improvement.
Alternative data collection methods	Use of new data collection methods, such as surveys and case studies.	Validate the hypotheses raised and expand the database for more robust empirical studies.
Cultural and economic comparison	Analyze the application of OEE and TPM in different cultural and economic contexts.	Identify the variables that influence the effectiveness of maintenance practices in different regions.
Integration with other Lean philosophies	Investigate the OEE and TPM integration with other Lean methodologies.	Evaluate the synergy and benefits of integrating multiple continuous improvement methodologies.
Predictive OEE	Develop OEE predictive models for management.	Provide detailed, real-time insights into production status to improve decision-making.
Cost-benefit analysis	Study of the operational costs and benefits of OEE and TPM practices.	Determine the cost-benefit ratio of OEE and TPM implementations in different industries.
Measurement of additional factors	Inclusion of additional factors such as equipment age and process productivity.	Improve the accuracy of OEE measurements by considering a wider range of variables.

Authors Contribution

R. C. dos Anjos: Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft; A. C. Dzulinski: Conceptualization, Methodology, Software, Validation, Writing - reviewing and editing, Supervision, Project administration; L. S. Goecks: Investigation, Validation, Formal analysis, Data curation, Writing- reviewing and editing.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary Material

Supplementary material associated with this article can be found online at: https://doi.org/10.18226/23185279.e251401.

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