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Review

Overview of predictive condition based maintenance research using bibliometric indicators

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ABSTRACT

This study uses bibliometric analysis techniques to provide an overview of the research conducted in the condition based maintenance (CBM) sciences. The paper objective is to determine the most influential research that has been conducted in this field. In this paper, a methodology is proposed. First, collect the articles using Web of Science based on selected keywords from 1970 to December 31, 2017. Next, determine the most influential journals, articles, keywords, authors, and institutions in CBM. Then, the analysis of country has been performed to analyze CBM studies with respect to its geographical distribution. Finally, The VOSviewer software is used to visualize the bibliographic material through co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation analysis. The outcomes of the study show that Wang W from China has been the most effective researcher, citations, and common reference with other authors in the subject of CBM. The USA was solely the most effective country in the subject of CBM. Centre National De La Recherché Scientifique is the most influential organization in this field. Finally, Berenguer C has the greatest co-authorship among the other authors considered.

Contents

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1. Introduction

In the late 1940s, the Rio Grande Railway Steel Company introduced the concept of CBM, and at the beginning, it was called "predictive maintenance". The railway company used CBM techniques to check the refrigerant, oil and fuel leak in the engine through the variable changes in pressure and temperature readings. Monitoring techniques of CBM have achieved a great success in terms of reducing the impact of unplanned failures and set a date to repair the leak or refill the coolant or oil hole. The US armed forces have captured this thought early and later adopted by major maintenance strategy to maintain its military equipment (Prajapati et al., 2012).

During the period of the 1950s, 1960s, and early 1970s, the concepts and applications of CBM in many industries such as space, automotive, military equipment, and major industries have emerged where CBM concepts have been embraced and showed many benefits in both efficiency and cost savings. Now many and large companies and organizations are interested in the concepts and applications of CBM including the US Defense Department (air force, navy, army, marines) and other companies like General Motors, Honeywell, Digitech, Honda, General Electric. Included developments in the field of information technology rapid development in the field of CBM technology by enabling display the bandwidth, data collection, retrieval, and analysis of data and capabilities to support decision-making for huge data sets of time series data measures. Target data that have been monitored from a plane or any system that can give a deeper look at the performance of the system, system state, the root cause of the failure of the system, along with an estimate of the remaining useful life of the system or subsystem. This serves as a huge advantage to keep the extremely important systems used in military, space, and marine fields, the industry of plane, automotive, and other industries. These huge and important applications and advantages have made CBM as the main potential area for the application of the company's production line - whether aircraft, vehicles and weapons systems or other products that require periodic maintenance. These industries are concentrating on concepts of CBM and maintenance methodologies and strategies by designing, planning and agents of CBM to enable the actors in the current and future systems engineering (Prajapati et al., 2012).

In this study, a general overview of the condition based maintenance (CBM) sciences is presented using bibliometric analysis indicators. The aim of the bibliometric analysis indicators is to measure the size and impact of publications and articles of other formats based on the count of scientific papers published and citations received. Bibliometric indicators are important for use in evaluation processes at universities, as well as public and private research institutions, for making decisions regarding funding, appointments, and the establishment of promotions and incentives for researchers (Merigó et al., 2015). In recent years, bibliometric indicators have been used in various research fields, such as inclusive management (Podsakoff et al., 2008), econometrics (Baltagi, 2007), health economics (Wagstaff and Culyer, 2012), marketing (Seggie and Griffith, 2009), statistics (Genest and Guay, 2002), ecological economics (Hoepner et al., 2012), ant colony optimization (Deng and Lin, 2012), pricing research (Leone et al., 2012), entrepreneurship (Landström et al., 2012), production and operations management (Holsapple and Lee-Post, 2010; Pilkington and Meredith, 2009), data envelopment analysis (Liu et al., 2013), gray systems (Yin, 2013), innovation (Fagerberg et al., 2012), fuzzy research (Merigó et al., 2015), and green supply chain management (Fahimnia et al., 2015). However, studies that use bibliometric indicators to focus on the analysis of the CBM field have not yet been presented.

The purpose of this study is to provide an overview of the research conducted in the field of CBM by means of an analysis using bibliometric indicators. The study herein reveals the most influential and productive research on the subject of CBM based on the information collected from Web of Science (WoS). The results are presented in terms of the number of articles published, the number of papers published by authors, the important keywords and journals in the field, and the key institutions/universities and countries involved in CBM research. Some limitations are expected in the research herein due to the fact that solely the WoS database has been used as the source of bibliometric indicators, and thus, any related works published in conferences and journals not listed in WoS have been excluded. Therefore, this study aims to be useful to display the current outcomes found in WoS regarding CBM.

2. Research methodology and initial data statistics

It is essential to choose the appropriate techniques and methods when analyzing data. To ensure the integrity of data, the means of approaching the analysis depends on the information supplied by the WoS database. WoS incorporates numerous databases for tending to this data. WoS is the focus of this study, as it considers a many sub-information databases, such as the Conference Proceedings Citation Index. WoS incorporates studies from all of the known sciences and currently contains data from more than 60 million papers in at least 15,000 journals and more than 250 topic categories in approximately 150 research fields. Although Google Scholar and Scopus include many other information databases, we solely focused on WoS in this study.

2.1. Notations

AEI:	Advanced Engineering Informatics
AUT:	AUTOMATICA
CI:	Computers in Industry
CIE:	Computers & Industrial Engineering
EB:	Energy and Buildings
EIMR:	EKSPLOATACJA I NIEZAWODNOSC MAINTENANCE AND RELIABILITY

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EJOR:	European Journal of Operational Research
H:	h-index
H-CBM:	h-index for CBM
H-CBM10:	The h-index in the last ten years for CBM
IEEEEIM:	IEEE Electrical Insulation Magazine
IEEETASE:	IEEE Transactions on Automation Science and Engineering
IEEETDEI:	IEEE Transactions on Dielectrics and Electrical Insulation
IEEETIA:	EEE Transactions on Industry Applications
IEEETIE:	IEEE Transactions on Industrial Electronics
IEEETPD:	IEEE Transactions on Power Delivery
IEEETPE:	IEEE Transactions on Power Electronics
IF:	impact factor in 2016
IJAMT:	International Journal of Advanced Manufacturing Technology
IJMTM:	International Journal of Machine Tools & Manufacture
IJOPM:	International Journal of Operations & Production Management
IJPE:	International Journal of Production Economics
IJPR:	International Journal of Production Research
INF:	INFOR
INS:	Insight
JIM:	Journal of Intelligent Manufacturing
J-old:	the first year of journal publication
JORS:	Journal of the Operational Research Society
MEA:	Measurement
MPE:	Mathematical Problems in Engineering
PIMEPJRR:	Proceedings of the Institution of Mechanical Engineers Part O Journal of Risk and Reliability
QREI:	Quality and Reliability Engineering International
R:	Rank
RE:	Renewable Energy
T50:	number of papers in the selected top 50 list
TC:	total citations
TC10:	total citations within the last 10 years
TC-CBM:	Total citations in CBM
TC-CBM10:	The citations in the last ten years for CBM
TP:	total papers
TP10:	total papers within the last 10 years
TP-CBM:	Total publications in CBM
TP-CBM10:	The total papers in the last ten years for CBM
%P-CBM:	Percentage of CBM papers in the journal

2.2. Defining the appropriate search terms

The keywords used for data collection include "Condition," "Based Maintenance," "Predictive," and "Maintenance." Four combinations of these keywords were used, including "Condition Based Maintenance," "Predictive Condition Based Maintenance," "Condition Maintenance," and "Predictive Maintenance." CBM can be defined mainly from two perspectives: monitoring and controlling. We ensured that these aspects were covered by the keywords chosen, such as system monitoring, preventive maintenance, equipment failure behavior data acquisition, data processing, maintenance decision making, diagnostics, prognostics, CBM of multi-unit systems, CBM of production systems, residual life estimation of systems subject to condition monitoring, and CBM of partially observable systems.

Table 1
Initial search results in all document types.

Search keywords	(Number of papers)
"Condition Based Maintenance"	1911
"Predictive Maintenance"	1145
"Condition Maintenance"	88
"Predictive Condition Based Maintenance"	2
Total	3146 papers

Table 2
Search results in article and review document types.

Search keywords	(Number of papers)
"Condition Based Maintenance"	1057
"Predictive Maintenance"	628
"Condition Maintenance"	31
"Predictive Condition Based Maintenance"	2
Total	1718 papers

2.3. Initial search results

Using the "Topic" search in the WoS database, we collected only the articles instead of all document types (Article, Proceedings Paper, Review, Editorial Material, News Item, Meeting Abstract, Letter, Note, Correction Addition, and Correction) for the defined search terms. The initial search attempts resulted in a total of 3146 articles. The search results for the four sets of keywords are shown in Table 1. We then focused on the search results of both document types, article and review, which are shown in the Table 2. To avoid repeated results and unrelated to CBM articles, we then generated a basic search using the following: topic: ("Condition Based Maintenance") or topic: ("Predictive Maintenance") or topic: ("Condition Maintenance") or topic: ("Predictive Condition Based Maintenance"). Then we refined the search step by step by document types (Article or Review), and the timespan was chosen to be all years. The total number of results after this refinement was 1718.

An additional manual search using "Cited Reference Search" has been developed to avert the omission of key research in this field. However, some papers can easily be omitted when analyzing every production in this area, specifically, in light of the fact that it is not clear where the limits exist between CBM and other related fields. In December 2017, there were approximately 1718 papers that used our topics, journal articles and reviews; this number covers all the papers contained in the WoS database. More particularly, the amount of CBM research is increasing, as shown by the trends of recent years in Fig. 1. This increase can also be explained by the growth in the quantity of publishers worldwide and by the development of the WoS database, which now incorporates numerous journals. However, the impact of the expansion of CBM research is shown by the establishment of new CBM journals and other associated ones that have recently been indexed in the WoS. Fig. 1 shows that the percentage of CBM papers out of the overall quantity of papers in the database is increasing every year. Specifically, the ratio of the number of CBM papers in a given year to the number of published papers in that same year [number of WoS CBM papers of year X (NCBMP) / total number of WoS papers of year X (TNP), where X is a given year] has increased. Currently, at least 100 publications are being distributed in this subject area each year, considering more than 261 publications were distributed in 2017, as shown in Fig. 1. Regarding citation count and according to the specific standards, this field has a normal rate of citation. The paper by Jardine et al. (2006) has received more 1000 citations, and presently, it is the most cited paper of all time, maintaining the first position in the journal of Mechanical Systems and Signal Processing (MSSP). Fig. 1 shows the number of

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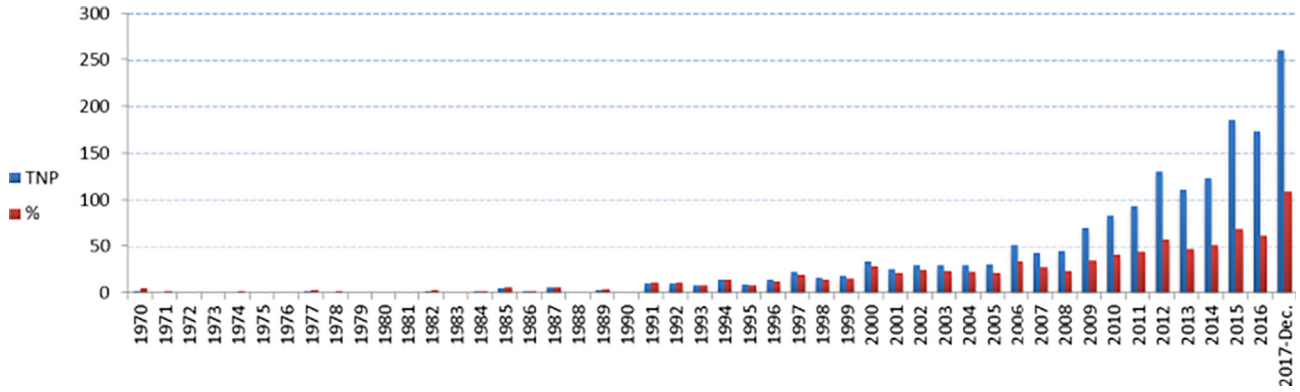

Fig. 1. Number of publications per year in CBM (articles + reviews) from 1970 to 2017. The total number of CBM papers per year are denoted in the blue bars, and the red bars indicate the ratio (NCBMP/TNP) × 1,000,000.

Table 3
General citation structure in CBM in WoS.

Citations	Number of papers	% Papers
≥100 citations	39	2.27
≥50 citations	77	4.48
≥20 citations	229	13.33
<20 citations	1373	79.92
Total	1718 papers	

publications per year in CBM (articles + reviews) from 1970 to 2017. The total number of CBM papers per year are denoted in the blue bars, and the red bars indicate the ratio (NCBMP/TNP) × 1,000,000. Table 3 shows that fewer than 2% of the papers have received at least one hundred citations. Additionally, most of the papers (over 80%) fall within the category of those having received fewer than 20 citations.

3. Twenty most influential journals in CBM

When surveying the journals containing CBM papers, the 20 most effective journals were examined (see Table 4). According to the rate of CBM papers published and the CBM h-index, the journals of Reliability Engineering & System Safety (RESS), MSSP, and IEEE Transactions on Reliability (IEEETR, where IEEE refers to Institute of Electrical and Electronics Engineers) have higher average citation rates than other journals, as shown in Table 4. To assess the citation rate of papers, the general citation structure of all publications is presented, arranged by many limits concerning the number of citations. The rate of papers in every area is also included. Moreover, it is important to analyze the global h-index, which is suggested by Martínez et al. (2014). The objective of the h-index is to measure the importance of a set of publications (Hirsch, 2005). For instance, if a group of papers has an h-index of 10, then 10 of the articles included in the set have received at least 10 citations. Furthermore, this means that there are 10 papers having at least 10 citations. Research in the CBM sciences is published in a wide range of journals (ranging in the hundreds). Additionally, Table 4 shows the impact factor as a measure of the quality of each journal, which is a measure of the frequency with which an "average article" from a given journal has been cited in a particular year or period. The impact factor is covered in the Journal Citation Reports in the WoS database. Note that The impact factor is a measure of the frequency with which the "average article" in a journal has been cited in a particular year or period. The annual journal impact factor is a ratio between citations and recent citable items published. Thus, the impact factor of a journal is calculated by dividing the number of current year citations to the source items published in that journal during the previous two years. For RESS impact factor in 2016, the impact factor of a journal

Table 4
Twenty most influential journals in CBM.

R	Name	CBM					TP	IF
		TP-CBM	TC-CBM	H-CBM	% P-CBM	T50		
1	RESS	107	3285	35	2.33	7	4583	3.153
2	MSSP	68	4024	28	1.61	8	4235	4.116
3	IEEETR	61	1637	23	1.52	4	4009	2.79
4	IJAMT	32	559	10	0.25	3	12,946	2.209
5	IJPR	31	544	12	0.34	1	9004	2.325
6	PIMEPJRR	29	126	7	6.84	0	424	1.084
7	EJOR	28	1431	19	0.18	4	15,348	3.297
8	ESA	27	416	15	0.24	0	11,160	3.928
9	CIE	24	340	10	0.38	1	6314	2.623
10	IEEETIA	22	419	11	0.24	1	9137	2.937
11	JIM	22	306	9	1.25	0	1763	3.035
12	CI	20	751	12	0.90	3	2224	2.691
13	MPE	19	61	3	0.19	0	10,097	0.802
14	QREI	18	155	7	0.96	0	1867	1.366
15	INS.	18	68	4	0.84	0	2136	0.527
16	IJPE	16	569	9	0.28	2	5778	3.493
17	IEEETPD	15	200	9	0.18	0	8242	3.218
18	IEEETDEI	14	447	8	0.29	1	4782	2.115
19	EIMR	13	58	5	1.99	0	654	1.145
20	MEA.	13	91	5	0.28	0	4679	2.359

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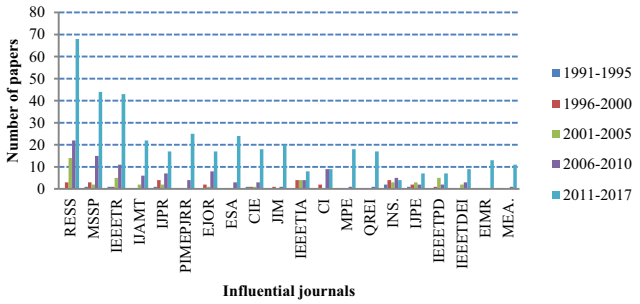

Fig. 2. Trend analysis for influential journals.

would be calculated as follows: 2016 impact factor = A/B. where: A = the number of times that all items published in that journal in 2014 and 2015 were cited by indexed publications during 2016. B = the total number of "citable items" published by that journal in 2014 and 2015. ("Citable items" for this calculation are usually articles, reviews, proceedings, or notes; not editorials or letters to the editor). Trend analysis for influential journals is presented in Fig. 2. It is worth noting that, the twenty most influential journals are started to publish of CBM searches in 1991. It can be observed that, all most influential journals have published increasingly through the periods from 1991 to 2017, and they have published more than ever in the period from 2011 to 2017 except insight journal.

4. Most influential articles in CBM

An important issue when analyzing published CBM research is to characterize the publications as indicated by the number of aggregate citations received. Hence, it is essential to determine which publications have received more references in this area. Though numerous perspectives may influence the valuation of an article, the number of citations received reflects the impact that a given article has in the scientific community. Table 5 presents the 50 most cited papers in CBM. Note that in 2006, the paper by Jardine, Lin et al. is the most cited and effective, having received 1312 citations and thus, appears in our list of the most influential authors in CBM. Also, the classic papers by Heng, Zhang et al., Si, Wang et al., Van Noortwijk; et al., and Saha, have received hundreds of citations. Note that some authors appear in more than one instance on the list.

5. The research areas of CBM papers

In this section, Fig. 3 shows the research areas of CBM papers. "Engineering", "Operations research management", and "Computer science" are the three major research areas studied in CBM subject, with around 64% of the total articles. This has improved the relationship of the research study along with the research areas. Trend analysis for research areas is presented in Fig. 3. It is worth noting that, the ten most research areas are started to be considered in CBM searches in 1970. It can be observed that, all most research areas have considered increasingly through the periods from 1970 to 2017, and they have considered more than ever in the period from 2015 to 2017.

6. Most influential keywords in CBM

Analyzing which keywords are the most influential is important, as it provides an effective measure of the influence of CBM research across the community. Table 6 displays the most popular keywords from the 50 most cited papers, the frequency of the keyword's occurrence, and the most influential paper for each keyword in CBM. It is worth noting that the keyword "Condition-based maintenance" has appeared 12 times in the 50 most selected papers, and the keywords "Maintenance" and "Prognostics" have occurred eight times, while the other keywords have less successful performance.

7. Overview of the most productive and influential authors

Defining the researchers according to the most presence and effect in the subject of CBM is significant when trying to obtain an overall representation of the subject area. Table 7 presents a list of the top 20 researchers with the greatest number of articles in the CBM community. The objective is to identify the greatly active authors in the CBM sciences, while identifying those highest ranked and most effective in this field. Observation of the quantity of publications alone is not fully informative because many limitations should be considered, such as the journal quality, the size of each paper, and the number of authors per paper. Thus, several other indicators are provided in the columns of Table 7 to offer a more detailed illustration of the authors in the CBM subject area. As shown in Table 7, Wang W is the most influential author in CBM research with approximately 34 papers and 1525 citations. Regarding his whole publication record, we find that he has received at least 1748 citations in 63 articles. Additionally, Zio E received a large number of citations in 550 total publications; however, with regards to the subject of CBM, the number of citations he has received ranges in the hundreds, while having 26 total papers. In addition, Jardine AKS has received more citations than Wang W in the subject CBM and in his whole publication record, although he has published fewer CBM papers than Wang W. In addition, a column was included in Table 7 to analyze the overall number of citations received by each author.

For monitoring the influence of the articles written by the best authors within the CBM society, a ranking of their articles according to four selected journals that serve as the major outlets of CBM articles is given in Table 8. The best four journals were selected according to the total number of citations and the percentage of total of CBM papers. We found that most of the authors have published in at least one of the four selected journals. Wang W has published in all selected journals with 8 papers. Berenguer C and Grall A every one of them have published 11 papers in the selected journals. The RESS journal has received the most number of papers when compared to the other selected journals, it has received 46 papers, ten of these papers are published by Grall A. Regarding the IEEETR and IJAMT journals, it is found that these journals have received fewer publications; they only contain 24 and 9 papers, respectively.

Table 9 presents the 20 most contributing authors, which are those who have the highest numbers of articles published in the four selected journals. Grall A presents as the top author for the RESS journal with ten published papers. Additionally, Zio E has the most complete profile across these four journals, he has published in three journals. Moreover, Berenguer C maintains the second position in the RESS journal and is among one of those in the second position in the IEEETR journal. Finally, although Jardine AKS does not appear among the top 20 contributing authors in CBM, he has the first position in the MSSP journal. Trend analysis for influential authors is presented in Fig. 4 It is clear that most of the publications of the influential authors started after 2000. It is worth noting that, the 20 most influential authors are started to publish in CBM searches in 2000. In addition, it can be observed that, all most influential authors were published increasingly through the periods from 2000 to 2017, and they have published more than ever in the period from 2012 to 2017.

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Table 5
50 most cited papers of all times in CBM.

R	Journal	TC	Title of paper	Year	C/Y	R	Journal	TC	Title of paper	Year	C/Y
1	MSSP	1312	A review on machinery diagnostics and prognostics implementing condition-based maintenance	2006	109	26	MSSP	120	Condition-based maintenance of machines using Hidden Markov Models	2000	7
2	EJOR	411	Remaining useful life estimation - A review on the statistical data driven approaches	2011	59	27	IJAMT	119	Current status of machine prognostics in condition-based maintenance: a review	2010	15
3	RESS	357	A survey of the application of gamma processes in maintenance	2009	40	28	RESS	118	A condition-based maintenance policy with non-periodic inspections for a two-unit series system	2005	9
4	MSSP	351	Rotating machinery prognostics: State of the art, challenges and opportunities	2009	39	29	EJOR	118	Sequential condition-based maintenance scheduling for a deteriorating system	2003	8
5	IEEETDEI	272	Review of modern diagnostic techniques for assessing insulation condition in aged transformers	2003	18	30	CIE	117	An overview of time-based and condition-based maintenance in industrial application	2012	20
6	CI	226	Intelligent prognostics tools and e-maintenance	2004	16	31	EJOR	117	Maintenance of continuously monitored degrading systems	2006	10
7	MSSP	219	Analysis of computed order tracking	1997	10	32	IJPR	115	HMMs for diagnostics and prognostics in machining processes	2005	9
8	MSSP	210	Prognostic modelling options for remaining useful life estimation by industry	2011	30	33	IJAMT	114	System health monitoring and prognostics - a review of current paradigms and practices	2006	10
9	RE	208	Condition monitoring of wind turbines: Techniques and methods	2012	35	34	IEEETIE	112	Machine Condition Prediction Based on Adaptive Neuro-Fuzzy and High-Order Particle Filtering	2011	16
10	RESS	203	A condition-based maintenance policy for stochastically deteriorating systems	2002	13	35	RESS	111	Reliability-centered predictive maintenance scheduling for a continuously monitored system subject to degradation	2007	10
11	HR	185	Methods for fault detection, diagnostics, and prognostics for building systems - A review, part I	2005	14	36	MSSP	107	A Wiener-process-based degradation model with a recursive filter algorithm for remaining useful life estimation	2013	21
12	MSSP	177	Prognostics and health management design for rotary machinery systems-Reviews, methodology and applications	2014	44	37	CI	107	SIMAP: Intelligent System for Predictive Maintenance – Application to the health condition monitoring of a wind turbine gearbox	2006	9
13	IEEETR	177	Continuous-time predictive-maintenance scheduling for a deteriorating system	2002	11	38	AEI	106	Research issues on product lifecycle management and information tracking using smart embedded systems	2003	7
14	IJPE	174	Selection of optimum maintenance strategies based on a fuzzy analytic hierarchy process	2007	16	39	INF.	100	A control-limit policy and software for condition-based maintenance optimization	2001	6
15	RESS	171	Condition-based maintenance optimization by means of genetic algorithms and Monte Carlo simulation	2002	11	40	RESS	99	Simulation modelling of repairable multi-component deteriorating systems for 'on condition' maintenance optimization	2002	6
16	IJPE	163	Linking maintenance strategies to performance	2001	10	41	IEEETASE	95	Sensory-updated residual life distributions for components with exponential degradation patterns	2006	8
17	AEI	160	Robust performance degradation assessment methods for enhanced rolling element bearing prognostics	2003	11	42	IEEETIA	95	Insulation failure prediction in AC machines using line-neutral voltages	1998	5
18	EB	159	Infrared thermography for building diagnostics	2002	10	43	IJOPM	92	Developing integrated solution offerings for remote diagnostics A comparative case study of two manufacturers	2009	10
19	IEEETPE	158	Failure prediction of electrolytic capacitors during operation of a switch mode power supply	1998	8	44	RE	91	Condition based maintenance optimization for wind power generation systems under continuous monitoring	2011	13
20	IEEETR	146	Remaining Useful Life Estimation Based on a Nonlinear Diffusion Degradation Process	2012	24	45	CI	89	Research issues on closed-loop PLM	2007	8
21	EJOR	143	On the application of mathematical models in maintenance	1997	7	46	IEEETR	88	An inspection-maintenance model for systems with multiple competing processes	2005	7
22	MSSP	136	A segmental hidden semi-Markov model (HSMM)-based diagnostics and prognostics framework and methodology	2007	12	47	IEEETR	88	Real-time performance reliability prediction	2001	5
23	IEEEEIM	128	Applications of dielectric spectroscopy in time and frequency domain for HV power equipment	2003	9	48	IJMTM	87	A review by discussion of condition monitoring and fault-diagnosis in machine-tools	1994	4
24	AUT.	128	On-board component fault detection and isolation using the statistical local approach	1998	6	49	RESS	86	Ensemble of data-driven prognostic algorithms for robust prediction of remaining useful life	2012	14
25	IJAMT	124	Intelligent predictive decision support system for condition-based maintenance	2001	7	50	JORS	84	Towards a general condition based maintenance model for a stochastic dynamic	2000	5

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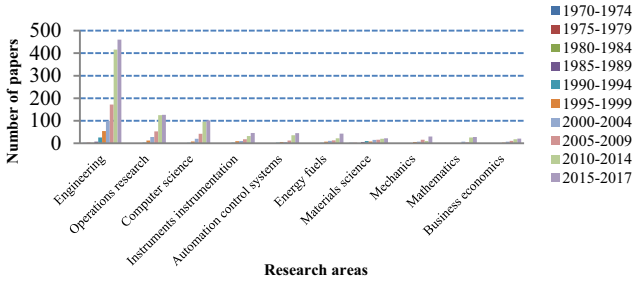

Fig. 3. The research areas of CBM papers.

8. Most productive and influential institutions

The 20 most powerful and effective organizations that contribute to the CBM studies are shown in Table 10. The acquired h-index indicates which organizations are most highly effective among the CBM studies. It should be noted that only the publications with the four keywords in these contributing organizations are analyzed. To evaluate the studies provided by these institutions, we examined the h-index and the total papers and citations in the last ten years. CNRS gets the most notable outcomes for the TP-CBM and H-CBM criteria. Organizations from both the China and France appear six and five times among the top 20 respectively. In summary, there are ten European institutions in the top 20, seven Asian institutions, and three American institutions. In Table 11, we present the institutions with the highest number of publications effectively devoted to the CBM sciences among the four journals selected. Some of contributing organizations has appeared in all four selected journals among the top 10 contributing organizations, such as City University of Hong Kong. CNRS upholds the second position in the top 10 contributing organizations in the CBM sciences, as it appears three times in the top 10 contributing organizations in the four selected journals. It is also noted that institutions from the USA, at times, maintain all the top positions.

9. Analysis by country

Research is an essential factor that decides the development of countries. The objective of this section is to analyze the study of CBM with respect to its geographical distribution. This can be of interest because authors may relocate to several different loca-

Table 6
Most popular keywords in 50 most cited papers in CBM.

R	Word	Frequency Word	The most influential paper	R	Word	Frequency Word	The most influential paper
1	Condition-based maintenance	12	(Jardine et al., 2006)	14	Degradation	2	(Saha, 2003)
2	Maintenance	10	(Van Noortwijk, 2009)	15	Gamma process	2	(Van Noortwijk, 2009)
3	Prognostics	9	(Jardine et al., 2006)	16	Hidden Markov Model (HMM)	2	(Baruah and Chinnam*, 2005)
4	Predictive maintenance	6	(Lee et al., 2006)	17	Maintenance cost optimization	2	(Grall et al., 2002)
5	Diagnostics	4	(Jardine, et al. 2006)	18	Maintenance management	2	(Swanson, 2001)
6	Reliability	4	(Heng et al., 2009)	19	Neural network	2	(Yam et al., 2001)
7	Remaining Useful Life (RUL)	4	(Si et al., 2011)	20	Nonlinear drift	2	(Zhang et al., 1994)
8	Replacement	4	(Grall et al., 2002)	21	PLM	2	(Kiritsis et al., 2003)
9	Identification	3	(Zhang et al., 1994)	22	Power plant	2	(Yam et al., 2001)
10	Markov process	3	(Van Noortwijk, 2009)	23	Proportional hazards model	2	(Si et al., 2011)
11	Optimisation	3	(Zhou et al., 2007)	24	Reliability centered maintenance	2	(Lee et al., 2014)
12	Inspection	2	(Van Noortwijk, 2009)	25	Statistical methods	2	(Basseville, 1997)
13	Aging	2	(Saha, 2003)				

Table 7
Top 20 contributing authors in CBM.

R	Author Name	TP-CBM	TC-CBM	H-CBM	TP10	TC10	T50	TP	TC	H
1	Wang W	34	1525	18	59	1230	4	63	1748	22
2	Zio E	26	550	10	251	3318	1	357	5790	38
3	Berenguer C	25	1065	14	35	566	4	57	1608	22
4	Makis V	25	439	10	33	351	1	68	1310	22
5	Grall A	23	864	12	20	175	4	36	1090	17
6	Hu CH	16	846	8	79	1567	3	83	1628	19
7	Lee J	14	862	10	30	875	4	38	1560	18
8	Tian ZG	14	471	11	31	830	1	38	1129	22
9	Zhou DH	14	935	9	98	2186	0	132	3506	33
10	Coit DW	13	90	6	40	703	0	84	3915	31
11	Jardine AKS	13	1763	11	23	281	2	56	2410	20
12	Barros A	12	228	6	24	289	0	26	344	12
13	Fouladirad M	12	193	7	24	236	0	25	260	9
14	Dong M	12	425	10	53	506	2	65	980	16
15	Galar D	12	60	3	33	118	0	33	118	7
16	Si XS	12	791	6	37	1112	3	37	1112	16
17	Banjevic D	11	1668	8	36	550	2	44	2132	16
18	Carnero MC	11	181	6	16	96	0	21	239	8
19	Ni J	11	407	8	33	284	1	113	2925	33
20	You MY	11	100	5	17	141	0	17	141	6

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Table 8
Total papers from the top 20 contributing authors among the four selected journals.

R	Author Name	IEEETR	IJAMT	MSSP	RESS	TP-CBM	Oth. CBM	Total
1	Wang W	2	1	2	3	34	26	63
2	Zio E	3	0	3	5	26	15	357
3	Berenguer C	3	0	0	8	25	14	57
4	Makis V	0	2	1	0	25	22	68
5	Grall A	1	0	0	10	23	12	36
6	Hu CH	0	0	1	0	16	15	83
7	Lee J	0	1	3	0	14	10	38
8	Tian ZG	3	0	2	1	14	8	38
9	Zhou DH	6	0	1	1	14	6	132
10	Coit DW	1	2	0	2	13	8	84
11	Jardine AKS	0	0	5	0	13	8	56
12	Barros A	3	0	0	4	12	5	26
13	Fouladirad M	0	0	0	6	12	6	25
14	Dong M	0	2	4	0	12	6	65
15	Galar D	0	0	0	0	12	12	33
16	Si XS	1	0	1	2	12	8	37
17	Banjevic D	0	0	4	1	11	6	44
18	Carnero MC	0	0	1	3	11	7	21
19	Ni J	0	1	0	0	11	10	113
20	You MY	1	0	0	0	11	10	17

Table 9
The top 20 contributing authors in the four selected journals.

R	IEEETR		IJAMT		MSSP		RESS	
	Author	TP	Author	TP	Author	TP	Author	TP
1	Barros A	3	Coit DW	2	Jardine AKS	5	Grall A	10
2	Berenguer C	3	Dong M	2	Mathew J	5	Berenguer C	8
3	Chen MY	3	Feng QM	2	Banjevic D	4	Fouladirad M	6
4	Ghasemi A	3	Liao WZ	2	Dong M	4	Zio E	5
5	Hu CH	3	Makis V	2	Lee J	3	Barros A	4
6	Huang HZ	3	Pan ES	2	Ma L	3	Dieulle L	4
7	Li YF	3	Xi LF	2	Tan ACC	3	Carnero MC	3
8	Tian ZG	3	Al-Raheem KF	1	Zio E	3	Deshpande VS	3
9	Xu ZG	3	Angeles J	1	Baraldi P	2	Do P	3
10	Zerhouni N	3	Arab A	1	De Villiers JP	2	Jiang R	3
11	Zio E	3	Azadeh A	1	Heng A	2	Modak JP	3
12	Compare M	2	Babishin V	1	Heyns PS	2	Pandey MD	3
13	Fan HD	2	Bae SJ	1	Heyns T	2	Parlikad AK	3
14	Gouriveau R	2	Bae SM	1	Lin DM	2	Pedregal DJ	3
15	Huynh KT	2	Baidya R	1	Liu QM	2	Tinga T	3
16	Ji YD	2	Banerjee P	1	Ompusunggu AP	2	Van Der Weide JAM	3
17	Liu Y	2	Campos J	1	Peng Y	2	Wang W	3
18	Medjaher K	2	Catteneo C	1	Pham HT	2	Asadzadeh SM	2
19	Ouali MS	2	Colosimo BM	1	Sun Y	2	Azadeh A	2
20	Pecht MG	2	Dehombreux P	1	Tian ZG	2	Basten RJI	2

tions, and therefore, a researcher may have papers from many countries. This is of importance particularly in the USA and in the UK, as these nations have received many researchers from locations throughout the world. Therefore, their production record is much higher than it would otherwise be if only the residents from their original nations were presented. Because every foundation is viewed as a group inside the country, the focus herein is on the publications indicated under the name of the establishment, as opposed to the first nationality of the authors. The outcomes are shown in Table 12. The ranking depends on the total number of paper published of the country in the CBM field. The USA is the most powerful and effective nation of the top ten countries in CBM because it has been publishing since 1974, and it has an h-index of 43 with more than 6700 citations in 398 papers. Although China more recently became one of the ten top countries in 2000, it maintains the second position with an h-index of 35 and approximately 5173 citations in 356 papers. This indicates that China is progressing quickly, and in the future, it could possibly surpass the USA and assume the first position. The third position goes to France, which is the same of Canada regarding the h-index. Additionally, France has published more total papers than Canada, but France has received fewer total citations. Finally, Australia has come in the end position of the top ten countries in CBM research.

10. Mapping of CBM research using the VOSviewer software

A graphical representation of the CBM research articles is provided in this section. The graphs create a visual means of assessing the common work and occurrence of authors, organizations, and documents. The VOSviewer software visualizes the bibliographic material through co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation analysis. An explanation and visual representation of all these bibliographic materials is presented in the following paragraphs. Note that the graphs present only those variables that mostly meet the bibliographic parameters (Merigó et al., 2016).

10.1. Co-authorship

It shows the volume of publications that are contained in a set of variables (authors, organizations, and countries) and how they

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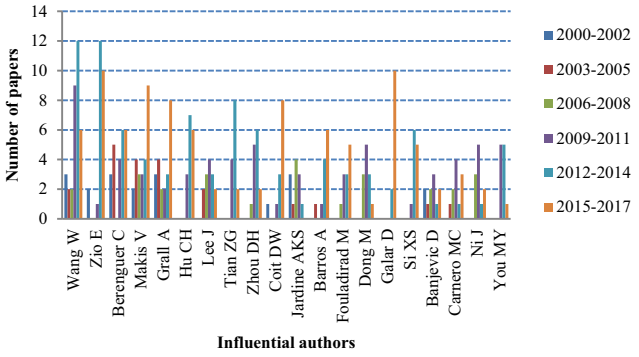

Fig. 4. Trend analysis for influential Authors.

are connected. Each circle represents a set with the largest circles representing a stronger link within a corresponding set, which indicates the number of times a given corresponding set is repeated in the selected field. Additionally, the lines between the circles represent repetitions with the thickest lines representing the strongest relation (co-authorship). Fig. 5 shows that Berenguer C has the greatest co-authorship among all other authors. Berenguer C exists 39 times with other authors in all his 25 published articles; for example he published nine articles with Grall A. In addition, Hu CH comes in the second position having 38 instances of co-authorship, and seven of them are with Zhou DH. Moreover, the most papers by these two authors were published within the intervals of 2009–2015, as shown in Fig. 5

10.2. The co-authorship between organizations

It is shown in the Fig. 6. Among all organizations publishing in the field of CBM, Polytechnic University of Milan has the strongest co-authorship with other organizations. It has 40 co-authorships with other organizations, and the most co-authorships were with Ecole Cent Paris and Supelec, having 11 and nine co-authorships, respectively. Although City University Hong Kong maintains the second position with 37 total links of co-authorship, it has more co-authorship links than Polytechnic University of Milan. Note that the total strength of the link represents the relationships of co-authorship, and it does not indicate the number of publications (the set may have more than one co-authorship in the same paper, while co-authorship may also not exist). It should be noted that we

Table 10
Top 20 contributing organizations in CBM.

R	Name	Country	H-CBM10	TP-CBM10	TC-CBM10	TP-CBM	TC-CBM	H-CBM
1	Centre National De La Recherché Scientifique CNRS	France	19	56	987	66	1598	19
2	Shanghai Jiao Tong University	China	15	47	694	54	1016	18
3	University of Technology of Troyes	France	12	28	478	40	1278	18
4	University of Toronto	Canada	9	26	300	40	2064	15
5	Polytechnic University of Milan	Italy	10	33	348	35	618	11
6	City University of Hong Kong	China	15	24	1125	26	1257	16
7	Cranfield University	England	9	25	272	26	274	9
8	Georgia Institute of Technology	USA	8	16	330	23	598	12
9	University Paris Saclay Comue	France	8	23	251	23	251	8
10	Beihang University	China	6	22	203	22	203	6
11	Centralesupelec	France	8	22	245	22	245	8
12	Xi AN Jiaotong University	China	7	21	300	22	326	8
13	University of Science Technology Beijing	China	10	21	943	21	943	10
14	Universidad De Castilla La Mancha	Spain	6	12	275	19	459	8
15	Tsinghua University	China	11	17	931	18	991	12
16	Lulea University of Technology	Sweden	6	17	119	17	119	6
17	University of Salford	England	7	7	578	17	1157	15
18	Concordia University Canada	Canada	11	16	484	16	484	11
19	Ecole Superior Electrical Supelec	France	7	16	198	16	198	7
20	National University of Singapore	Singapore	9	15	304	16	313	9

Table 11
Top 20 contributing organizations in the four selected journals.

R	IEEETR		IJAMT		MSSP		RESS	
	Institution	TP	Institution	TP	Institution	TP	Institution	TP
1	Centre National De La Recherche Scientifique CNRS	7	Shanghai Jiao Tong University	6	Shanghai Jiao Tong University	7	University of Technology of Troyes	17
2	Tsinghua University	7	University of Toronto	3	University of Toronto	6	Centre National De La Recherche Scientifique CNRS	16
3	University of Electronic Science Technology of China	5	Chongqing University	2	Queensland University of Technology QUT	5	Delft University of Technology	5
4	University of Technology of Troyes	4	Rutgers State University New Brunswick	2	Centre National De La Recherche Scientifique CNRS	4	Polytechnic University of Milan	5
5	City University of Hong Kong	3	University of Cincinnati	2	City University of Hong Kong	4	Universidad De Castilla La Mancha	4
6	Concordia University Canada	3	University of Houston	2	Xi An Jiaotong University	4	Centralesupelec	3
7	Polytechnic University of Milan	3	Caledonian Coll Engineering	1	Centralesupelec	3	Changsha University of Science Technology	3
8	University of Alberta	3	Changwon National University	1	Ecole Nationale Superieure De Mecanique Et DES Microtechniques	3	City University of Hong Kong	3
9	Alstom	2	City University of Hong Kong	1	Ecole Superior Electrical Supelec	3	Eindhoven University of Technology	3
10	Centralesupelec	2	Cranfield University	1	Polytechnic University of Milan	3	Ku Leuven	3

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Table 12
Top 10 countries in CBM.

R	Name	TP-CBM	TC-CBM	H-CBM	TP-CBM10	TC-CBM10	H-CBM10	Since
1	USA	398	6774	43	240	2899	29	1974
2	China	356	5173	35	327	3939	31	2000
3	France	157	3062	29	116	1506	22	1992
4	England	142	2630	25	100	1639	18	1984
5	Canada	131	3861	29	97	1635	24	1987
6	Spain	90	1108	18	70	748	15	1997
7	Italy	75	1076	18	61	620	15	1981
8	South Korea	55	666	14	46	578	12	1993
9	Netherlands	49	1154	16	39	826	12	1995
10	Australia	48	1416	16	36	947	11	1987

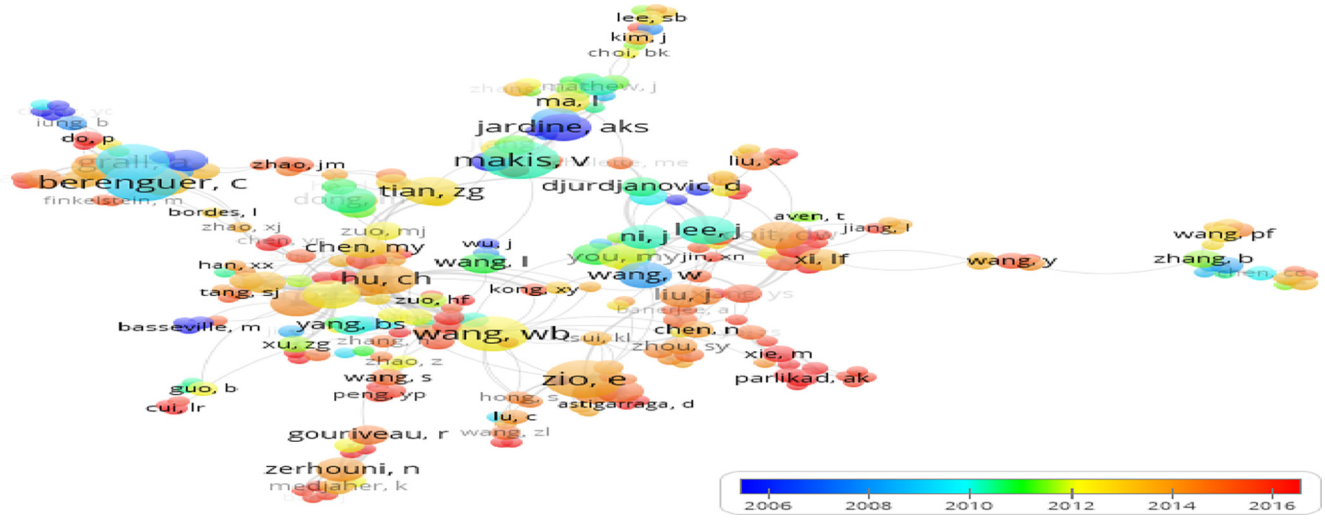

Fig. 5. Co-authorship between authors in CBM.

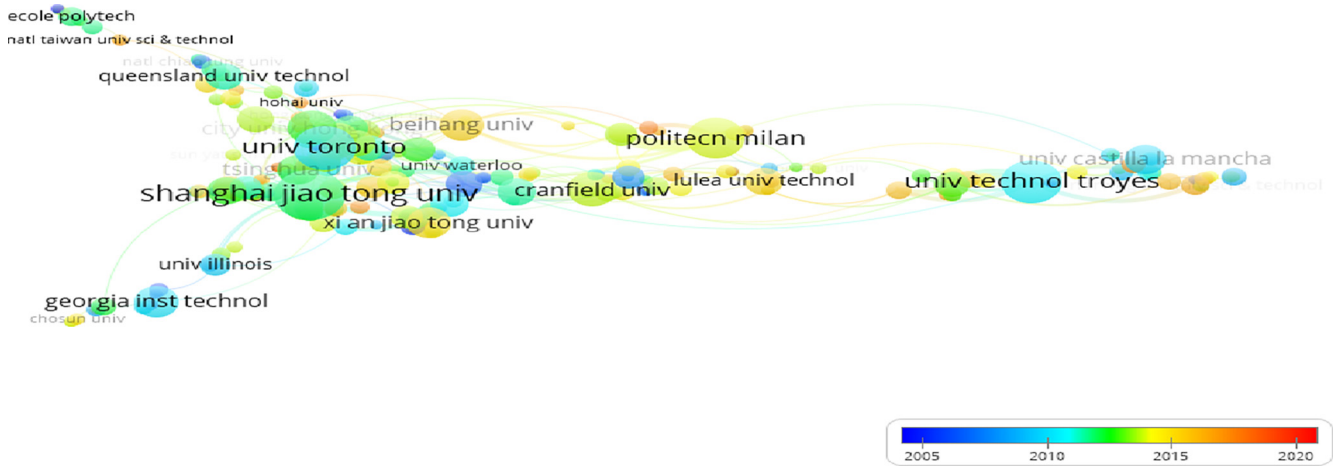

Fig. 6. Co-authorship between organizations in CBM.

have eliminated some organizations because they have a few co-authorships between organizations, and therefore, they do not appear in Fig. 6

10.3. Co-occurrence

It indicates the number of times that a keyword appears in the documents considered. In Fig. 7, we have included keywords frequently used in the CBM field. Author keywords (the keywords that appear on the first page of many journals) are considered to help visualize the relationships among keywords and their common existence in the same paper. Fig. 7 shows that the keywords examined in this study have the strongest occurrence (existence in papers considered) and have the strongest link (common existence with other keywords). For example, the "Condition-Based Maintenance" or "Condition Based Maintenance" keywords have 232 and 54 common occurrences, and a total link strength of 368 and 83 with other keywords, respectively. The keyword "Condition

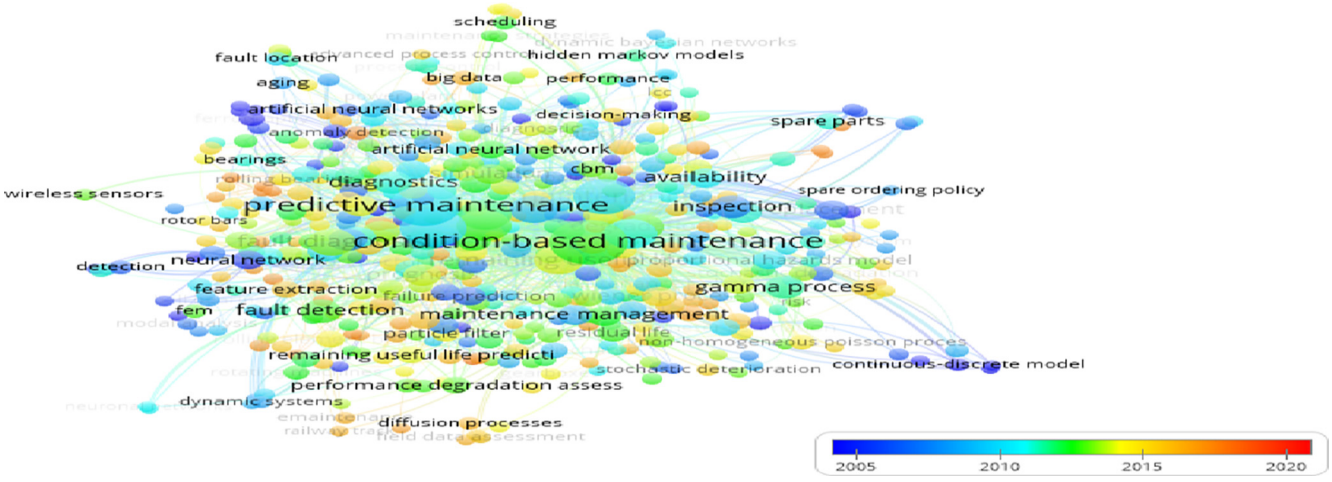

Fig. 7. Co-occurrence author keywords in CBM.

Monitoring" has the second position with 134 common occurrences and a link strength of 265. "Predictive Maintenance" maintains the third position. Also, many of keywords appear in Fig. 7, such as "Maintenance," "Prognostics," "Reliability," "Remaining Useful Life," etc., but the most common occurrence is with "Condition-Based Maintenance," which means there is a strong relationship between CBM and maintenance research. Additionally, it should be noted that the keywords mostly appear between the years of 2005 and 2010

10.4. Citation

It measures the direct citations between two variables in the considered set (documents, sources, authors, organizations, or countries). For example, with two authors, the connection represents the number of times author X has cited Y plus the number of times that author Y has cited X among the set of documents considered. Note that Fig. 8 illustrates the two documents that give the citation but does not represent the third document that receives the other two citations. Fig. 8 shows the citation relationships among authors. Wang W is the author who received and cited others the most in his 34 papers, having more than 1500 citations and a total link strength of more than 1400 between the other authors. The authors Si XS and Hum CH have total link strengths of 51 and 50, respectively. In addition, Fig. 8 shows that Berenguer C maintains the second position; he has received and cited others in his 25 papers, having more than 1060 citations with a total link strength of 945. For example, he has the most citations with Grall A with a link strength of 62, a link strength of 34 with Barros A, and a link strength of 34 with both of Huynh KT and Fouladirad M. Although Banjevic D and Jardine AKS have more than 1660 citations, they have total link strengths of 744 and 737, respectively.

10.5. Bibliographic coupling

It is the connections shown between the chosen variables (documents, sources, authors, organizations, or countries) that cite the same documents. However, the presence of a bibliographic coupling does not necessarily indicate that co-authorship exists. Fig. 9 illustrates where two connected documents appear; however, the relationship to a third document is not presented unless it has a significant degree of bibliographic coupling through other documents. In Fig. 9, the bibliographic coupling between authors is shown. The results show that Wang W has the most common reference with other authors with a total link strength of 25,931. Note that link strength indicates the instances he and another author have cited a third author at the same time. He has cited the same authors with Hu CH by 1447 times, who maintains the second position with a total link strength of 22,927. In addition, Wang W has cited the same authors with Zhou DH 1245 times, who

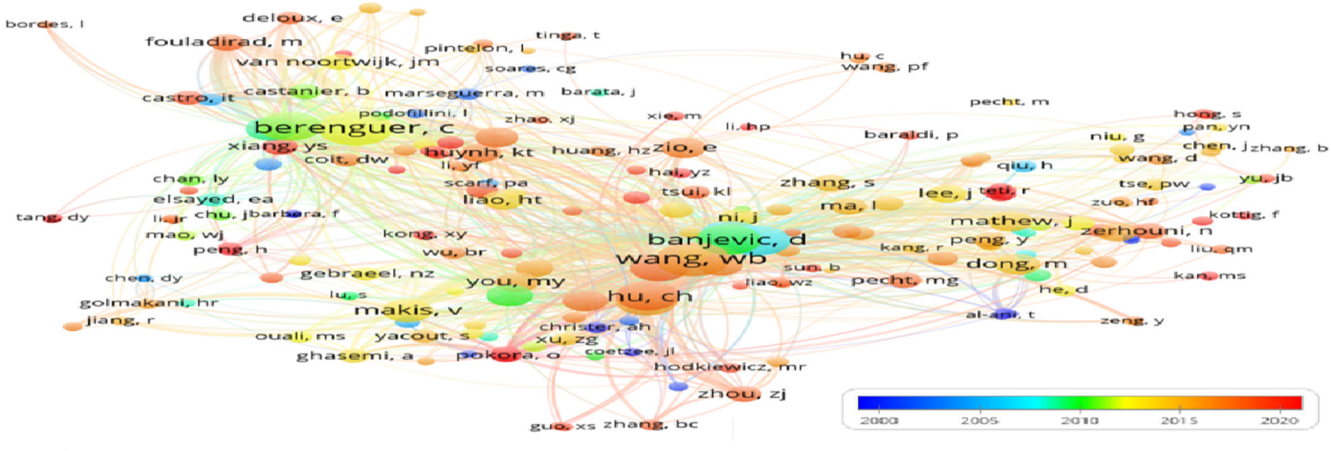

Fig. 8. Citation between authors in CBM.

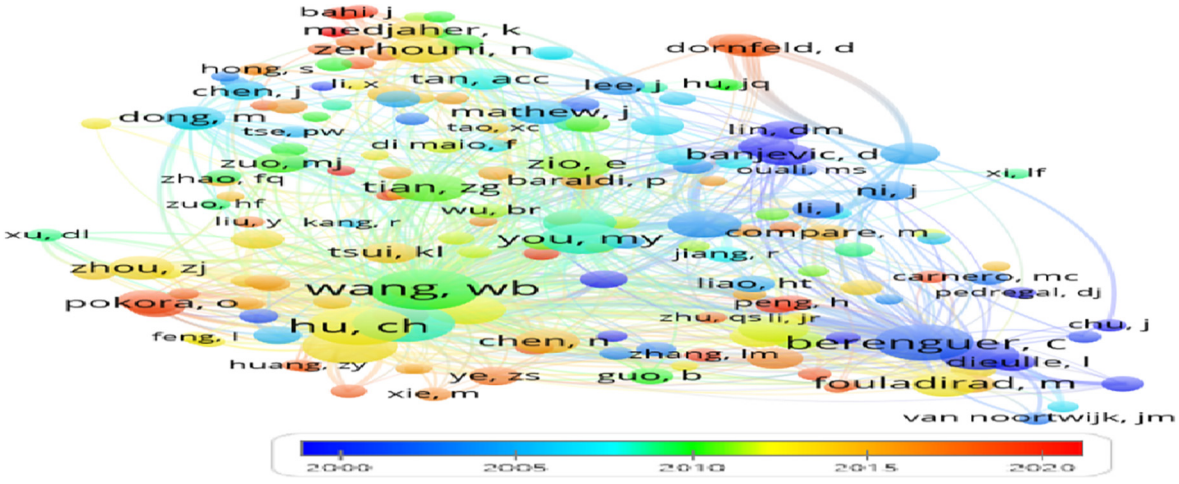

Fig. 9. Bibliographic coupling of authors that publish in CBM.

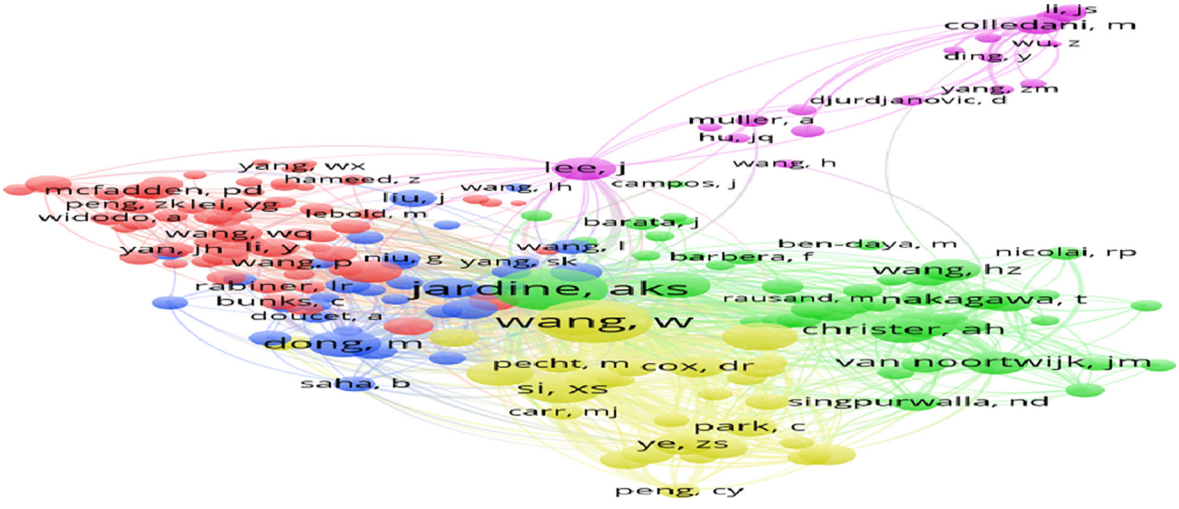

Fig. 10. Co-citation of authors cited in CBM.

comes in the third position with a total link strength of 21,456. Finally, Berenguer C comes in the fourth position with a link strength of 20,212.

10.6. Co-citations

They are an interesting issue is to consider, and here we discuss the co-citation of authors. Co-citations indicate the authors that have received the highest number of citations in the CBM subject and how their profile is connected to other authors. Fig. 10 presents the leading co-cited authors of CBM research. Wang W is the most cited author in the subject of CBM with a total link strength of more than 6470, closely followed by Jardine AKS with a total link strength of 6277. Thus, these two authors represent the core of this study. However, some other authors also reach a notable position, including Si XS, Wang W, and Dong M.

11. Conclusions

In this paper, a general study of CBM research has been introduced utilizing bibliometric methods. The results indicate that the research in this field experiences a high level of variability with respect to nations, as there are several effective nations in the CBM research field. In earlier years, the USA was solely the most effective country in the subject of CBM, having begun its publishing in 1974 and presenting authors with many publications and citations. Today, there are numerous effective nations due to the increase in study groups that have been generated in the USA, European, and Asian countries. It is clear that, until now, Wang W from China has been the most effective researcher in the subject of CBM. Apart from Wang W, there are several other effective researchers from other countries, including Zio E, Berenguer C, Makis V, and Grall A. The first CBM paper by Trotter JA was published in 1970 and has the title "techniques of predictive maintenance". CNRS is the most persuasive and influential organization in this field, and the most popular authors in the field of CBM have been affiliated with this organization. Thus, a significant issue to note is that there are three of the effective institutions working on CBM hypotheses that exist in the top 100 of the Academic Ranking of World Universities (ARWU). These four effective institutions are the University of Toronto, Tsinghua University, Georgia Institute of Technology, and National University of Singapore, which have ARWU rankings of 23, 48, 85, and 91 in 2017, respectively. In this study, the top 20 contains ten institutions from European countries, seven institutions from Asian countries, and three institutions from America.

Although this study has given a general bibliometric review of CBM research, there are a few limitations that ought to be noted. The data displayed here is instructive and provides a general introduction of the most beneficial and powerful research in the CBM

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field. Thus, numerous exceptions to the findings herein may exist because of the particular nature of the research considered. For instance, some authors may acquire a higher number of articles due to a high level of co-initiation, while some others may distribute papers individually. Thus, the distribution of 10 papers from a principal type of researcher is not identical to the production of 10 papers from a secondary researcher. Citations are likewise affected by these issues. For instance, a paper may be less cited than other papers due to its exploration of a highly specific subject matter. This is common in the CBM sciences, since it is an interdisciplinary field that incorporates numerous experience levels of authors with various citation rates between them.

Additionally, significant data may be excluded when addressing bibliometric data in light of publications and citations in the scientific field, as the data relies on upon different issues that cannot be directly evaluated, such as the contributions to journals, conferences, and associations. Thus, this study endeavors to recognize some key research in CBM hypotheses, while taking note of this challenge. Considering the data analyzed in this paper, numerous distinctions in the rankings could appear, dependent upon the particular issues considered, which may impact the articles, journals, authors, organizations, and countries considered herein.

Finally, we conducted a mapping analysis for the CBM research articles to determine how the researches are coupled. These maps showed that Berenguer C has the greatest co-authorship among the other authors considered. In addition, among the organizations publishing in CBM, Polytechnic University of Milan has the strongest co-authorship with other organizations. In the field of the co-occurrence of authors' keywords, the keywords considered in this study have the strongest occurrence (existence in papers considered) and the strongest link (common existence with other keywords). Regarding citations, Wang W has received the most citations and has cited others in his 34 papers that were included in this part of the analysis, having more than 1500 citations. With respect to bibliographic coupling, the results show that Wang W has the most common reference with other authors with a total link strength of 25,931. According to the co-citation of authors cited in CBM, Wang W is also the most cited author in the CBM with a total link strength of more than 6470.

Conflict of interests

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

Baltagi, B.H., 2007. Worldwide econometrics rankings: 1989–2005. Econometric Theory 23 (5), 952–1012.
Baruah, P., Chinnam*, R.B., 2005. HMMs for diagnostics and prognostics in machining processes. Int. J. Prod. Res. 43 (6), 1275–1293.
Basseville, M., 1997. On-board component fault detection and isolation using the statistical local approach, INRIA.
Deng, G.-F., Lin, W.-T., 2012. Citation analysis and bibliometric approach for ant colony optimization from 1996 to 2010. Exp. Syst. Appl. 39 (6), 6229–6237.
Fagerberg, J., Fosaas, M., Sapprasert, K., 2012. Innovation: exploring the knowledge base. Res. Pol. 41 (7), 1132–1153.
Fahimnia, B., Sarkis, J., Davarzani, H., 2015. Green supply chain management: a review and bibliometric analysis. Int. J. Prod. Econ. 162, 101–114.
Genest, C., Guay, M., 2002. Worldwide research output in probability and statistics: an update. Can. J. Stat. 30 (2), 329–342.
Grall, A., Bérenguer, C., Dieulle, L., 2002. A condition-based maintenance policy for stochastically deteriorating systems. Reliab. Eng. Syst. Saf. 76 (2), 167–180.
Heng, A., Zhang, S., Tan, A.C., Mathew, J., 2009. Rotating machinery prognostics: State of the art, challenges and opportunities. Mech. Syst. Sig. Process. 23 (3), 724–739.
Hirsch, J.E., 2005. An index to quantify an individual's scientific research output. Proc. Natl. Acad. Sci. U.S.A. 102 (46), 16569.
Hoepner, A.G., Kant, B., Scholtens, B., Yu, P.-S., 2012. Environmental and ecological economics in the 21st century: an age adjusted citation analysis of the influential articles, journals, authors and institutions. Ecol. Econ. 77, 193–206.
Holsapple, C.W., Lee-Post, A., 2010. Behavior-based analysis of knowledge dissemination channels in operations management. Omega 38 (3), 167–178.
Jardine, A.K., Lin, D., Banjevic, D., 2006. A review on machinery diagnostics and prognostics implementing condition-based maintenance. Mech. Syst. Sig. Process. 20 (7), 1483–1510.
Kiritsis, D., Bufardi, A., Xirouchakis, P., 2003. Research issues on product lifecycle management and information tracking using smart embedded systems. Adv. Eng. Inf. 17 (3), 189–202.
Landström, H., Harirchi, G., Åström, F., 2012. Entrepreneurship: exploring the knowledge base. Res. Pol. 41 (7), 1154–1181.
Lee, J., Ni, J., Djurdjanovic, D., Qiu, H., Liao, H., 2006. Intelligent prognostics tools and e-maintenance. Comput. Ind. 57 (6), 476–489.
Lee, J., Wu, F., Zhao, W., Ghaffari, M., Liao, L., Siegel, D., 2014. Prognostics and health management design for rotary machinery systems—Reviews, methodology and applications. Mech. Syst. Sig. Process. 42 (1), 314–334.
Leone, R.P., Robinson, L.M., Bragge, J., Somervuori, O., 2012. A citation and profiling analysis of pricing research from 1980 to 2010. J. Business Res. 65 (7), 1010–1024.
Liu, J.S., Lu, L.Y., Lu, W.-M., Lin, B.J., 2013. Data envelopment analysis 1978–2010: a citation-based literature survey. Omega 41 (1), 3–15.
Martínez, M., Herrera, M., López-Gijón, J., Herrera-Viedma, E., 2014. H-Classics: characterizing the concept of citation classics through H-index. Scientometrics 98 (3), 1971–1983.
Merigó, J.M., Gil-Lafuente, A.M., Yager, R.R., 2015. An overview of fuzzy research with bibliometric indicators. Appl. Soft Comput. 27, 420–433.
Merigó, J.M., Blanco-Mesa, F., Gil-Lafuente, A.M., Yager, R.R., 2016. Thirty years of the international journal of intelligent systems: a bibliometric review. Int. J. Intell. Syst.
Pilkington, A., Meredith, J., 2009. The evolution of the intellectual structure of operations management—1980–2006: a citation/co-citation analysis. J. Oper. Manage. 27 (3), 185–202.
Podsakoff, P.M., MacKenzie, S.B., Podsakoff, N.P., Bachrach, D.G., 2008. Scholarly influence in the field of management: a bibliometric analysis of the determinants of university and author impact in the management literature in the past quarter century. J. Manage. 34 (4), 641–720.
Prajapati, A., Bechtel, J., Ganesan, S., 2012. Condition based maintenance: a survey. J. Q. Maintenance Eng. 18 (4), 384–400.
Saha, T.K., 2003. Review of modern diagnostic techniques for assessing insulation condition in aged transformers. IEEE Trans. Dielectrics Electr. Insulat. 10 (5), 903–917.
Seggie, S.H., Griffith, D.A., 2009. What does it take to get promoted in marketing academia? Understanding exceptional publication productivity in the leading marketing journals. J. Market. 73 (1), 122–132.
Si, X.-S., Wang, W., Hu, C.-H., Zhou, D.-H., 2011. Remaining useful life estimation–a review on the statistical data driven approaches. Eur. J. Operational Res. 213 (1), 1–14.
Swanson, L., 2001. Linking maintenance strategies to performance. Int. J. Prod. Econ. 70 (3), 237–244.
Van Noortwijk, J., 2009. A survey of the application of gamma processes in maintenance. Reliab. Eng. Syst. Saf. 94 (1), 2–21.
Wagstaff, A., Culyer, A.J., 2012. Four decades of health economics through a bibliometric lens. J. Health Econ. 31 (2), 406–439.
Yam, R., Tse, P., Li, L., Tu, P., 2001. Intelligent predictive decision support system for condition-based maintenance. Int. J. Adv. Manuf. Technol. 17 (5), 383–391.
Yin, M.-S., 2013. Fifteen years of grey system theory research: a historical review and bibliometric analysis. Exp. Syst. Appl. 40 (7), 2767–2775.
Zhang, Q., Basseville, M., Benveniste, A., 1994. Early warning of slight changes in systems. Automatica 30 (1), 95–113.
Zhou, X., Xi, L., Lee, J., 2007. Reliability-centered predictive maintenance scheduling for a continuously monitored system subject to degradation. Reliab. Eng. Syst. Saf. 92 (4), 530–534.