International Joint Conference on Industrial Engineering and Operations Management- ABEPRO-ADINGOR-IISE-AIM-ASEM (IJCIEOM 2020)

Maintenance in the Industry 4.0 scenario: Systematic Review

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Abstract Smart machines and factories use advanced technologies such as networks, connected devices, data analysis and artificial intelligence to achieve more efficient predictive maintenance. With this scenario, we move from an environment where machines communicate with man, for machines communicating with machines and making decisions at all times, with a minimum number of human beings involved. Noting the importance of maintenance in the scenario of Industry 4.0, this article aims to study this context. Literature searches were carried out in three databases, Scopus, Science Direct and Web Of Science, and then a systematic literature review (SLR) supported with the software StArt. As a result, a total of 65 articles were found from the search for the keywords Industry 4.0, Maintenance Management, Maintenance 4.0 and Total Productive Maintenance and subsequently systematically revised based on the following inclusion and exclusion criteria. Therefore, it concludes the trend of using predictive maintenance and technologies such as cyber-physical systems (CPSs). As future work, it is suggested to conduct a study on maintenance management practices and tools for the context of Industry 4.0.

Keywords: Maintenance 4.0; Maintenance Management; Total Productive Maintenance; Industry 4.0.

1 Introduction

The maintenance strategy and concept affect the performance of machines and equipment. This is closely related to the productivity of manufacturing processes and the return on invested capital and the company's total profit (Rakyta et al., 2016). Historically, industrial maintenance began as a necessary evil, which means that maintenance operations were performed only when strictly necessary. However, in industrial manufacturing environments, often characterized as stochastic, dynamic and chaotic, maintenance is a crucial issue to ensure production efficiency (Cachada et al., 2018).

The company's paradigm shift, and intelligent manufacturing technologies, lead to the evolution and transformation of maintenance strategies and models, of predictive and prescriptive diagnosis (Ansari et al., 2019), leading to an environment of wide competition between different companies and the difference is in the small details, with the use of cyber systems, cloud storage or Internet of Things, resulting in the most advanced form of predictive maintenance (Poór et al., 2019).

Industry 4.0 creates a kind of revolution in the interaction between people and machines, where cooperation between man and robot will reach a higher level to the development of intelligent interfaces. In return, the maintenance team will be directed to the management of maintenance activities carried out by intelligent robots together with the dynamic development of modern technologies (Krason et al, 2019).

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Therefore, this study aims to investigate the academic progress of maintenance in the context of Industry 4.0, to investigate prominent journals, in addition to the summary of the main authors and their institutions. In addition, this article also includes the following research risks and the main search directions.

2 Methodology

To understand the development of research in the studied area, the method adopted in this work was a systematic literature review (SLR) with articles search made in Brazilian journal portal CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), specifically in the databases, Scopus, Web Of Science and Science Direct and included a period of 10 years of publications. Three combinations of research were carried out on the aforementioned databases to collect the maximum number of publications on maintenance in order to deepen knowledge about maintenance in the scenario of Industry 4.0.

This review was carried out with the support of the StArt software (State of the Art by Systematic Review) developed by LAPES/UFSCAR, to dynamically facilitate the organization and understanding of research development over the years (Table 1), including all relevant data for carrying out the analyzes, and following the research protocol.

Table 1. Steps taken to select articles

Requirements	Definition
Key words	*Maintenance 4.0, Total Productive Maintenance, Maintenance Management, Industry 4.0*
Search terms	*"Industry 4.0" AND "Maintenance Management"* *"Industry 4.0" AND "Maintenance 4.0"* *"Industry 4.0" AND "Total Productive Maintenance"*
Database used	*Scopus, Science Direct, Web of Science*
Exclusion Criteria (E)	Duplicate articles; Access blocked; Book, Abstract, Thesis or Website; Articles outside the 2010-2019 period; Articles that do not even contain in the Title, Abstract and Keywords the words contained in the search strings.
Inclusion Criteria (I)	Open access; Document type, article only; Articles in languages: English, Portuguese or Spanish; Maintenance approach in the Industry 4.0 scenario.

The research protocol was necessary to later identify the relevant scientific studies to be included in the systematic literature review (SLR), following the mentioned inclusion and exclusion criteria.

This research comprised a total of 65 articles (Fig. 1), with 7 articles found in the Science Direct database, which corresponds to 11% of the scientific researchers analyzed, 18 articles in the Web Of Science database (28%) and the database that most relevant research was found, with 40 articles, which corresponds to 62%, more than half of the studies analyzed, the Scopus base.

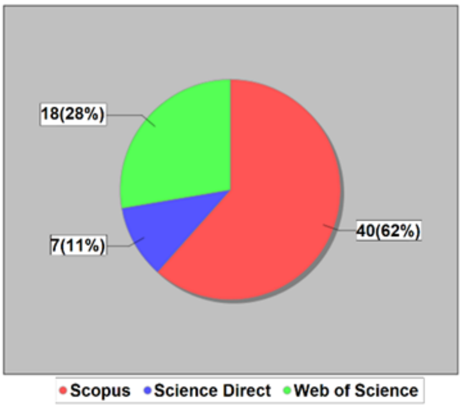

Fig. 1. Number of articles found per database. Source: StArt

According to the search protocol and combinations of search strings used to find articles by databases, it was observed that when combining "Industry 4.0" and "Maintenance Management", 47% of scientific studies totaled at Scopus (Table 2). On the other hand, 5 articles were found, from the three databases, combining "Industry 4.0" and "Total Productive Maintenance".

Table 2. Identification of articles.

Search string / Database	Scopus	Science Direct	Web of Science
Industry 4.0 and Maintenance 4.0	6	2	6
Industry 4.0 and Maintenance Management	31	5	10
Industry 4.0 and Total Productive Maintenance	3	0	2

At first, only articles published between the years 2010 to 2019 were selected, then the inclusion and exclusion criteria were applied, based on the reading of the title, abstract and keywords. Subsequently, the introduction and conclusion were read and finally, to carry out the systematic review, the complete readings of 26 articles were carried out. After applying the filters and criteria, 18 articles (33% of the articles) were excluded and 13 duplicate articles were found, corresponding to 26% of the total sample of articles analyzed. The review was carried out with 26 articles (Table 3).

Table 3. Article chosen for literature review

Title	Authors	Year
A predictive maintenance cost model for CNC SMEs in the era of industry 4.0	Adu-amankwa [1]	2019
Optimal maintenance thresholds to perform preventive actions by using multi-objective evolutionary algorithms	Goti et al. [2]	2019
PriMa: a prescriptive maintenance model for cyber-physical production systems	Ansari et al. [3]	2019
Manufacturing paradigm-oriented PHM methodologies for cyber-physical systems	Xia and Xi [4]	2019
Human Factor in Maintenance Management	Krason et al. [5]	2019
A RAMI 4.0 view of predictive maintenance: Software architecture, platform and case study in steel industry	Bousdekis et al. [6]	2019
Requirements for IT Systems of Maintenance Management	Blaszczyk and Wisniewski [7]	2019
A unified architecture for proactive maintenance in manufacturing enterprises	Bousdekis et al. [8]	2019
A BIM-based PSS approach for the management of maintenance operations of building equipment	Fargnoli et al. [9]	2019

The journey towards world class maintenance with profit loss indicator	Rødseth et al. [10]	2019
Predictive Maintenance 4.0 as next evolution step in industrial maintenance development	Poór et al. [11]	2019
Methodology of overall equipment effectiveness calculation in the context of industry 4.0 environment	Aleš et al [12]	2019
Embedding CSPC database with CPS to enhance toy product safety	Li et al. [13]	2019
Maintenance 4.0 Technologies for Sustainable Manufacturing - an Overview	Jasiulewicz-Kaczmarek and Gola [14]	2019
Enhancing smart maintenance management using fog computing technology	Ashjaei and Bengtsson [15]	2018
Cyber physical systems implementation for asset management improvement: A framework for the transition	Villar-Fidalgo et al. [16]	2018
Maintenance - Identification and analysis of the competency gap	Antosz [17]	2018
Maintenance 4.0: Intelligent and Predictive Maintenance System Architecture	Cachada et al. [18]	2018
Towards an open-standards based framework for achieving condition-based predictive maintenance	Kaur et al. [19]	2018
Research on operation and maintenance management of equipment under intelligent manufacturing	Cao [20]	2017
On the Advancement of Maintenance Management Towards Smart Maintenance in Manufacturing	Macchi et al. [21]	2017
The maintenance management in the macro-ergonomics context	Jasiulewicz-Kaczmarek et al. [22]	2017
Big data summarisation and relevance evaluation for anomaly detection in cyber physical systems	Bagozi et al. [23]	2017
Proactive approach to smart maintenance and logistics as a auxiliary and service processes in a company	Rakyta et al. [24]	2016
Maintenance 4.0 in railway transportation industry	Kans et al. [25]	2016
Industry 4.0-Potentials for Predictive Maintenance	Li et al. [26]	2016

3 Results

It was possible to notice the evolution of publications on maintenance in the scenario of Industry 4.0 (Fig. 2), which justifies the relevance of the research, however it is observed from the reading that there are still opportunities to be explored, by researchers and professionals from the corporate environment, as industries, so that you can share experiences and report on progress.

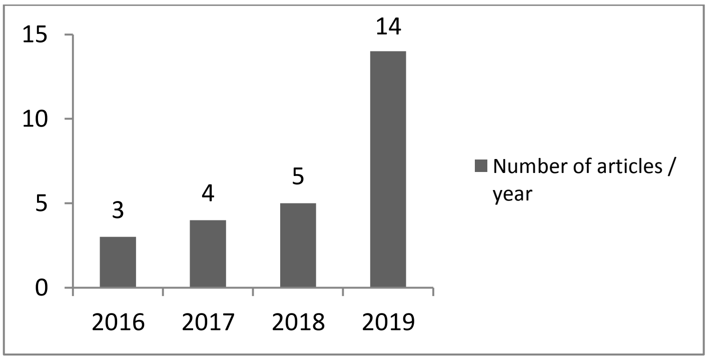

Fig. 2. Number of articles analyzed per year.

It was observed that the articles considered relevant to this research frequently present the words: Industry 4.0 and Maintenance Management. It is also noted that there is a tendency in the literature to explore Predictive Maintenance, a characteristic of the type of maintenance that is strongly applied in scenarios considered as Industry 4.0. Finally, the growing interest of academia in developing research in this area was also observed through the analysis of authors over the years, which shows a gradual increase with authors who publish in several years and also by authors who publish previous studies.

3.1 Maintenance in the context of Industry 4.0

Maintenance consists of overhauling, repairing and replacing components of a machine or equipment, in order to allow it to return to operation within the design specifications (Kelly and Harris,1978) Corrective maintenance is performed after an unwanted stop and aims to perform a repair action on the machine so that it returns to operation (Smith, 2011). Preventive maintenance is performed based on the time variable, with predefined intervals and with the objective of reducing the number of unwanted stops that degrade the equipment (Palmer, 2005). Predictive maintenance is performed by collecting information, sampling and monitoring the equipment, in order to reduce or minimize the number of unwanted stops that lead to equipment failure (Mobley, 2002). Proactive maintenance is a continuous process of actions that aim to extend the life of the equipment through actions to monitor and manage the main causes of failures (Rakyta et al., 2016).

Maintenance in the context of Industry 4.0 focuses on the ability of "intelligent" machines to autonomously provide statistical data on their physical processes, monitored by cyber-physical systems (CPSs) and equipped to make decisions based on feedback measured via sensors, microcontrollers and softwares (Adu-amankwa, 2019).

Smart machines and factories use advanced technologies such as networks, connected devices, data analysis and artificial intelligence to achieve more efficient predictive maintenance, with the goal of reducing failures and improving security, reliability, availability and efficiency (Adu-amankwa, 2019).

However, maintenance in the context of Industry 4.0 forms a subset of intelligent manufacturing systems, autonomous in their operation, capable of predicting failures and triggering maintenance activities. These systems are composed of intelligent equipment in the form of embedded or cyber-physical systems, forming the digital twin of physical assets. To achieve almost zero defects, almost zero downtime and automated decision making based on world-class condition monitoring, diagnostics and prognoses need to be implemented (Kaur et al., 2018).

In this scenario, the machines that have communicated with man will start to communicate with other machines and will make decisions all the time, with a minimum number of people involved monitoring the system in real time. Therefore, it was found that approximately 88% of articles emphasize predictive maintenance as a trend in this scenario, followed by preventive maintenance with 7% and proactive maintenance with 3% (Table 4). The analyzed articles showed no tendency regarding the use of corrective maintenance for the scenario of Industry 4.0. The methodology used in the analyzed articles was also observed, standing out with approximately 65% of case study and simulation, followed by 27% of conceptual theorist and, finally, 8% of the studies were carried out through research.

Table 4. Maintenance given focus by the authors.

Type of Maintenance	Technologies/Approach	Authors
Predictive	CPS, IoT, IoS, DATA MINING, BIG DATA, CNC, CMMS, TPM, E-MAINTENANCE, RCM, OEE, WCM, PSS, CBM	[1], [2], [3], [4], [5], [6], [7], [9], [10], [11], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [25], [26]
Preventive	TPM, OEE	[12]
Proactive	CPS, IoT, BIG DATA, E-MAINTENANCE	[8], [24]

In relation to enabling technologies in industry 4.0 and approaches to articles in predictive maintenance, Cyber-Physical Systems (CPS), Internet of Things (IoT), Internet of Services (IoS), Data

Mining (DM), Big Data and applications such as Computer Numerically Controlled (CNC), Computerized Maintenance Management System (CMMS), Total Productive Maintenance (TPM), E-Maintenance, Reliability Centred Maintenance (RCM), Overall Equipment Effectiveness (OEE), World Class Manufacturing (WCM), Product-service system (PSS) and Condition Based Maintenance (CBM). Approximately 54% emphasized the use of Cyber Physical Systems (CPS) and Internet of Things (IoT) to perform maintenance.

In preventive maintenance, a focus on Total Productive Maintenance (TPM) and Overall Equipment Effectiveness (OEE) was identified, while in proactive maintenance, Cyber-Physical Systems (CPS), Internet of Things (IoT), Big Data and E-Maintenance were found.

The technology used in maintenance in the context of Industry 4.0 was highlighted in the literature (Table 5). Note that most researchers report case studies and simulations using Cyber Physical Systems (CPS) and Internet of Things (IoT), followed by Big Data (BD), Internet of Services (IoS) and Data Mining (DM) , respectively. Three articles highlight the challenges in preparing people to work in the maintenance scenario in the context of Industry 4.0.

Table 5. Technologies given focus by the authors.

Technologies/Approach	Authors
Cyber Physical Systems (CPS)	[3], [4], [5], [6], [10], [11], [13], [16], [19], [21], [22], [23], [25], [26]
Internet of Things (IoT)	[2], [5], [6], [8], [10], [11], [14], [15], [18], [19], [22], [24], [25], [26]
Internet of Services (IoS)	[5], [26]
Data Mining (DM)	[5], [26]
Big Data (BD)	[3], [5], [6], [8], [15], [18], [19], [20], [23], [26]
Human Factor	[5], [17], [22]

In the study carried out by Adu-amankwa [1], they address the minimum representation of small and medium-sized enterprises (SMEs) in the literature, explicitly collecting data from SMEs and propose an economical predictive maintenance system architecture for CNC machine shops.

Blaszczyk and Wisniewski [7], Macchi et al. [21], Bagozi et al. [23] and Li et al. [26], highlight that maintenance management includes several activities, such as preventive maintenance planning, task scheduling and parts management, in order to identify and correct anomalies.

Poór et al. [11], Aleš et al [12], Li et al. [13], Macchi et al. [21] and Blaszczyk & Wisniewski [7], explore total productive maintenance within the Industry 4.0 scenario and review fundamental concepts of CPS and OEE applications.

Bousdekis et al. [8], Jasiulewicz-Kaczmarek et al. [22] and Kans et al. [25], explore the maintenance trend in the context of Industry 4.0 through e-maintenance, as a proactive maintenance technology based on real-time monitoring via the internet.

Poór et al. [11] and Macchi et al. [21] present forecasting opportunities, citing as the "new" with a focus on Reliability Centred Maintenance (RCM). Goti et al. [2], Ansari et al. [3], Cachada et al. [18] and Macchi et al. [21], present maintenance approaches and challenges in the context of Industry 4.0 with a focus on Condition Based Maintenance (CBM). Ansari et al. [3], contributes to production management and planning, introducing a new maintenance model (PriMa).

Fargnoli et al. [9], integrate approaches based on building information modeling (BIM) in a product service system (PSS) context to improve the management of construction equipment maintenance operations and Rødseth et al. [10], emphasize that having a maintenance function in the company that guarantees a competitive advantage in the world market requires world-class maintenance (WCM), based on predictive maintenance principles. Jasiulewicz-Kaczmarek & Gola [14] make a maintenance contribution to the construction of sustainable and competitive manufacturing in commercial operations.

As highlighted in the literature, maintenance in the context of Industry 4.0 has characteristics:

- Predominance of predictive maintenance based on data collection and machine information for continuous monitoring.
- Storage of machine information and knowledge in a virtual environment that allows access and analysis of data remotely.
- Emergence of multidisciplinary groups and initiatives involving not only the maintenance sector, but also production, finance, suppliers, for actions to mitigate problems that cause machine problems or process failures.

• And finally, as a result of real-time monitoring and the interconnection of systems with the involvement of trained people, the objective is for actions to take place immediately.

4 Conclusions

The industry is in a fast pace to absorb the benefits of Industry 4.0, but unfortunately the standards are not keeping up with this speed, so companies must develop characteristics of their own equipment management, building an intelligent factory that meets their real needs, to that these changes can bring more competitiveness to the factory. Being prepared for new concepts based on future requirements means being interested in the current situation, analyzing it and creating new visions and a new model of predictive maintenance systems.

The research analyzed in the ten years articles on maintenance in the context of Industry 4.0. It was found that, in addition to enabling technologies, the authors reinforce the gap in people's competence to act in this scenario. Regarding the enabling technologies of Industry 4.0, a trend was identified regarding the use of predictive maintenance practices, including Cyber Physical Systems (CPS) and Internet of Things (IoT).

Therefore, for future research, it is suggested to conduct a study on maintenance management practices and tools for the context of Industry 4.0.

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