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Implementation of Industry 4.0 technology: New opportunities and challenges for maintenance strategy

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Abstract

Industry 4.0 is revolutionizing decision-making processes within the manufacturing industry. Maintenance strategies play a crucial role to improve progressively technical performances and economical savings. The introduction of Industry 4.0 technology results in relevant innovations able to condition maintenance policies. Moreover, innovative solutions can be introduced, such as "remote maintenance" and the "self-maintenance".
In this paper, we investigate the state-of-the-art of technologies in a "smart factory" with the aim to understand how Industry 4.0 technologies are affecting maintenance policies and to discuss their implication in strategies.
We found important trends in maintenance policies, such as "remote maintenance" and the attractive option of the "autonomous maintenance". This study represents the first comprehensive investigation in these research themes, and it desires to produce a broader insight and knowledge of current trends and main difficulties, highlighting critical aspects and disadvantages for the implementation of innovative policies.

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1. Introduction

Industry 4.0 environment aims to introduce the so called "nine pillars" of advanced technologies within manufacturing process environment [1,2]. The most relevant technologies are constituted by Cyber Physical Systems

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(CPS) and the Internet of Things technology [3,4] able to transform a conventional factory into a digitalized or "smart factory" [5]. Such technological innovations also involve a relevant change in management for manufacturing, including maintenance strategies or policies.

According to [6], maintenance management is considered one of the first aspects to take into consideration in an Industry 4.0 environment to have both technical and economic advantages [6].

The aim of this study is to present the state-of-the-art of Industry 4.0 technologies able to affect maintenance policies and to discuss their implication in strategies and innovations.

In order to achieve this, first, a literature review of recent articles has been necessary. In fact, as demonstrated by recent literature [7-14], it let the authors to identify gaps in knowledge and provides theoretical foundations for the proposed study. The literature review section let the authors to identify and focus relevant research themes and investigate collected papers for answering to our aim of finding how Industry 4.0 technologies are transforming conventional maintenance policies. To the authors' best knowledge, no articles are today present in literature that investigate the state-of-the-art of Industry 4.0 technologies currently applied in maintenance policies.

Finally, the analysis presented in this paper desires to produce a broader insight and knowledge of current trends and main difficulties, highlighting critical aspects and disadvantages for the implementation of innovative policies based on Industry 4.0 technologies.

2. Methods

As first step to investigate the implications of Industry 4.0 technology in maintenance management, a literature review was carried out.

Research criteria consist of achieving the state-of-the-art of Industry 4.0 technologies and to understand how maintenance policies are changing for meeting its requirements.

Although the Industry 4.0 is dated 2011, the first relevant article, that matches with the aim of this work, is published in 2015 and the last one is dated in 2019.

The explored databases are Scopus, Google Scholar and Web of Science (WoS), mainly including articles in the engineering-manufacturing and using combinations of keywords like "industry 4.0", "maintenance", "maintenance policies" or "maintenance strategies". In particular, a further literature exploration was made through the use of key concepts emerged from the first examination, such as "remote maintenance" and the "self-maintenance".

Articles with title and abstract that fit the scope of our investigation have been collected and analyzed.

We collected a total of 25 papers published from 2015 to 2019. The main areas of publications are "Engineering", "Computer Science", "Mathematics" and "Decision Sciences".

The state-of-art framework is presented in Section 3. In the Results section (Section 4), implications of Industry 4.0 technologies in maintenance policies are presented. In Section 5 conclusion and discussion are given.

3. Industry 4.0 technology: state-of-art

As described in the Introduction section, Industry 4.0 involves the use of the so-called "nine pillars" of technologies. Such pillars include: 1) Industrial Internet of Things (IIoT); 2) Big Data; 3) Horizontal and vertical integration of systems; 4) Simulations; 5) Clouds; 6) Augmented Reality; 7) Autonomous Robots; 8) 3D printing and 9) Cyber Security.

The Industrial Internet of Things (IIoT) consists in the introduction of Cyber Physical Systems (CPS), that are interconnected systems via internet. They allow local or global data exchanging and they do not need any human interaction [15,16].

As defined by [17], Big Data is "the amount of data just beyond technology's capability to store, manage and process efficiently". In an Industry 4.0 environment, a relevant amount of digital data is collected in a real time from CPSs.

Horizontal and vertical system integration involves a total connection of all the players of the entire supply chain, making a highly dynamic system [18].

Simulations can be considered as a digital tool for assisting the design of production systems, and they are suitable for the optimization of real time data from CPSs [19].

Cloud technology includes both digital storage solution and cloud computing [5], enabling the sharing of data from CPSs in an "on-demand" way [20,21].
Augmented Reality (AR) is the technology able to merge, in a coherent way, the interaction between humans and CPSs, superimposing digital data on reality [22].
Robotic applications fit with a variety of services in a smart factory, helping the operators in their task and interacting with other cobots [23]. Robots also acquire data from inspection activities.
Additive manufacturing allows the 3D printing of physical objects. For instance, typical sources are represented by 3D CAD digital designs [24].
The last technology is represented by Cyber Security, that is defined as the intersections of intelligent systems with the aim to protect shared information from cyber-attacks [25].

4. Results

In addition to the identification of Industry 4.0 technologies able to play a role in maintenance strategies, the literature review also allowed us to investigate further research themes that include examples of implementation of innovative maintenance policies based on these technologies and related critical aspects.
As first, we highlighted how the amount of digital data available in a smart factory allows to enhance common maintenance strategies, as well as to develop new ones [26]. In fact, digital data represent an additional insight for management.
The predictive maintenance has been extensively studied during last thirty years by academic researchers and industrial practitioners [27]. Recent literature discusses several designs for predictive maintenance basing on Industry 4.0 main technologies, such as IIoT, Cloud Computing and Big Data Analytics [28]. Thanks to Industrial IIoT is possible to make prediction algorithms for predictive maintenance able to improve performance and quality [29], as well as minimizing costs [30].
The proactive maintenance is the strategy focused on monitoring not only symptoms but also causes of failure, and then it naturally takes advantages from a digitalized environment [31]. Indeed, its main feature is the "anticipation action", evolving from diagnosis, monitoring, prognosis, as well as the application of algorithms for decision-making [31].
[32] provides a guide for implementing proactive maintenance in an industrial context. Other authors suggest indexes for monitoring health devices in a smart factory [33,30]. The quantitative nature of such indexes is relevant for prognostic and, in general, for proactive maintenance, giving information about current status of a system, as well as previsions for future states.
[34] considers smart maintenance as a maintenance strategy enabled by Industry 4.0 technology and characterized by advanced analytics. The authors refer to it as "prescriptive maintenance". In the same context, [35] discusses a Cloud-based architecture for the storage of digital data coming from CPSs and implement an algorithm for a management strategy that operates from only one center of control.
Industry 4.0 fully supports the so-called Remote Maintenance, or "telemaintenance", especially through the use of Augmented reality technology [36,37].
A very attractive solution enabled by Industry 4.0 is represented by self-maintenance or autonomous maintenance strategy, basically supported by continuous and non-intrusive processes for monitoring system states [38,37]. According to [18], self-awareness and self-predictiveness have a key role in Industry 4.0 and, in relation to maintenance, they are able to limit the total number of shutdowns [39]. Self-maintenance is generally supported by the use of robot technology and such strategy is preferred by companies that deal with activities that involve high risk operations.
Finally, according to [40], we found that the role of the maintenance operator is changing, and it can consist in supervising the automated production, also through enhanced monitoring systems. The author also states how conventional interfaces for handling information are today unsuitable, and the reason should be found in the increased volume of digital data exchange in an Industry 4.0 environment.
Fig. 1 shows the trend analysis of papers that directly describe specific maintenance policies based on Industry 4.0 technologies. As it is possible to see, we found 4 papers for each of policies of *predictive maintenance*, *proactive maintenance* and *self-maintenance*. On the other hand, only two papers are related for both *smart maintenance* and *remote maintenance*.

Table 1 shows summarizes relevant aspects emerged from collected papers. They have been divided in *Policies based on Industry 4.0 technologies elements* and *critical aspects*. The first represents the list of innovative policies that can be potentially enabled by Industry 4.0 technology. Table 1 also shows disadvantages, or critical aspects, that mainly consist in addressing the complexity of technology and the need of advanced decision-making algorithms. Indeed, such algorithms are often demanded for advanced maintenance strategies implementation.

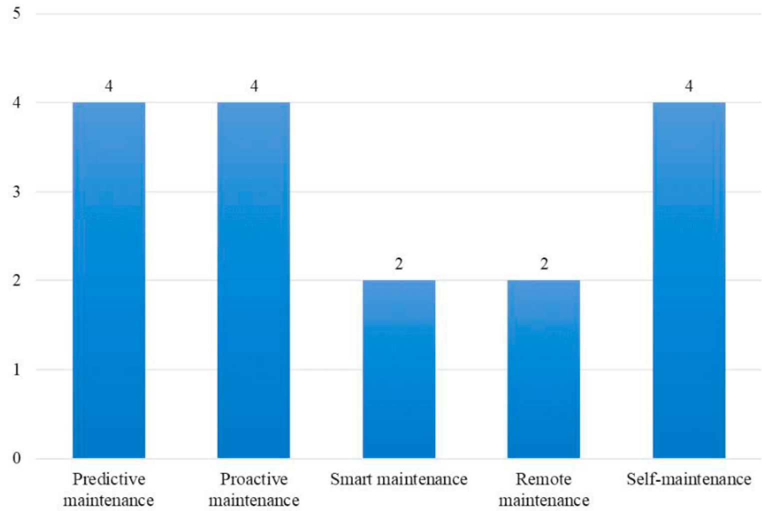

Fig. 1. Distribution of papers based on maintenance policies in an Industry 4.0 environment.

Table 1. Key aspects and disadvantages for the implementation of Maintenance 4.0.

	Maintenance policies
Policies based on Industry 4.0 technologies	*- Predictive maintenance* *- Proactive and prescriptive maintenance* *- Remote maintenance* *- Self-maintenance*
Disadvantages	*- Complexity of technology* *- Need of advanced decision-making algorithms* *- New roles for the maintenance operator*

5. Discussion and conclusion

The main purpose of this study was to investigate the state-of-the-art of Industry 4.0 technologies and to assess their implications in maintenance management and policies.

We found that Industry 4.0 has introduced relevant changes in processes and manufacturing systems, including maintenance strategies. It seems to be clear that maintenance is having a relevant reorganization in terms of policies, as well as the introduction of innovative modalities.

The perspective to achieve an efficient remote maintenance appears ever more realistic by means of Industry 4.0 technology such as augmented reality and autonomous robots coupled with effective big data analytic tools. This appears as a very attractive key and mostly useful for industries that deal with high risk activities.

As discussed in previous sections, Industry 4.0 technologies always meet the essential prerequisites of a predictive, proactive or prescriptive maintenance policy. In fact, innovative solutions, as remote or self-maintenance, are enabled by Industry 4.0 technology, offering to industrial practitioners, decision makers and senior managers the possibility to move from conventional policies towards more attractive and powerful solutions, such as the

autonomous maintenance.
However, the main limitation for maintenance strategy design appears to be related to the complexity of technology itself and the necessity of ever more advanced decision-making algorithms.
Undeniably, for providing companies in promoting the evolution of their maintenance policies, ever more reliable tools are needed, and research should continue in developing effective diagnostic and prognostic algorithms.
Finally, it appears evident how the role of the "maintenance operator" should adapt in a such technological environment, being able to supervise an automated production and advanced monitoring systems and user interfaces. At the same time, technologies such as smart devices can help the operator also in having an easier, effective and real-time information, contributing to the development of an efficient and safe maintenance.

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