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The role of Industry 4.0 enabling technologies for safety management: A systematic literature review

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Abstract

Innovations introduced during the Industry 4.0 era consist in the integration of the so called "nine pillars of technologies" in manufacturing, transforming the conventional factory in a smart factory.
The aim of this study is to investigate enabling technologies of Industry 4.0, focusing on technologies that have a greater impact on safety management. Main characteristics of such technologies will be identified and described according to their use in an industrial environment. In order to do this, we chose a systematic literature review (SLR) to answer the research question in a comprehensively way. Results show that articles can be grouped according to different criteria. Moreover, we found that Industry 4.0 can increase safety levels in warehouse and logistic, as well as several solutions are available for building sector.
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Keywords: Industry 4.0, Safety Management, Systematic Literature Review, Internet of Things

1. Introduction

Industry 4.0 is innovating manufacturing through the integration of the so called "nine pillars of technologies". Cyber Physical Systems (CPS) and the Internet of Things (IoT) are the most representative technologies for manufacturing processes [1,5], being the evolution of computerization and automation that characterized the third revolution [4].

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Such nine pillars allow the transformation of a conventional factory into a smart factory [6], and they comprise the following technologies: 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.
Maintaining a high level of safety in a factory is the utmost importance for the well-being of operators and technologies introduced by Industry 4.0 can have a great impact on safety management.
The aim of this study is to address the following research question:

- *What are the impacts did Industry 4.0 enabling technologies have on safety management?*

In order to do this, enabling technologies of Industry 4.0 were first investigated through the use of the Systematic Literature Review (SLR), focusing on their current or potential application for safety management. Main characteristics of such technologies will be identified and described according to their use in an industrial environment.

2. Materials and method

The SLR is widely considered as a powerful tool to investigate the current knowledge in relation to a specific research question. The difference between SLR and traditional review is that SLR is always conducted through a replicable, scientific, and transparent process [7], eliminating the risk of introduction of bias or non-critical evaluations [7-9]. In particular, SLR is performed following a methodology able to identify what is known and unknown for the given question [10]. Such methodology consists in the following steps: 1) the formulation of the research question; 2) the examination of literature review according to identified key themes; 3) the inclusion of articles that match with the research criteria; 4) the assessment of articles and their assortment in a database and 5) the extraction of results from the database and their discussion during the synthesis phase.
Our research was acquired from Scopus database (scopus.com) and only peer reviewed journal and international conferences has been included. The literature exploration was made through several research strings combined with each other with the Boolean <AND>. Research strings are listed in Table 2.
As mentioned before, selected articles were summarized in a database, that helped authors to characterize and assess studies according to the SLR question. The process for the inclusion of articles was first based on the screening of article titles, keywords, abstract and the final accurate review of the full text [11]. Furthermore, the process was conducted in three phases (Table 1 and Table 2), among which the first two differ for thematic areas explored. The third phase introduces some exclusion criteria. The considered timeframe is 10 years (2010-2020).

Table 1. Research steps considered for the inclusion of papers.

	Research Areas
Step 1	*Engineering, Computer science, Management and Accounting, Business.*
Step 2	*Engineering, Computer Science.*
	Exclusion Criteria
Step 3	*Documents that differ from Articles and Review Articles typology* *Documents written in language other than English*

Table 2. Relative number of papers for considered research strings and research phase.

Research Strings	Step 1	Step 2	Step 3
"Internet of things" AND "safety management"	117	102	39
"additive manufacturing" AND "safety management"	0	0	0
"augmented reality" AND "safety management"	19	14	6
"cloud" AND "safety management"	135	93	32
"big data analytics" AND "safety management"	14	12	4
“Horizontal e vertical integration” AND “safety management”	0	0	0
"cyber security" AND "safety management"	14	9	3
Total	299	230	84
Removing duplicates	276	211	68

3. Industry 4.0 technologies: state of art

As mentioned in the Introduction section, Industry 4.0 enabling technologies are grouped in the so called “nine pillars” list. Nine 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) introduce within the factory Cyber Physical Systems (CPS). They consist in systems connected via internet, allowing a fast exchange of data in a local or global scale and without human intervention [12-17]

Such digital transformations are continuously growing, in particular for industrial automation, and deep changes are expected for models, paradigms and industrial processes strategies [18-24].

In [25] Big Data are defined as “the amount of data just beyond technology's capability to store, manage and process efficiently”. A “digital” factory allows the collection of a conspicuous amount of data that can be manageable by Big Data.

According to the Forrester definition, Big Data is made up of four parts: Volume of data, Variety of Data, Velocity of generation of new data and analysis, Value of Data [26]. Furthermore, Big Data, CPSs and Cloud are able to generate an industrial network and its coordination allows to create a smart factory [27,28]

Horizontal and vertical system integration is possible through a total interconnection among all players that constitute the supply chain, transforming it in a higher dynamic system [29].

In particular, the Horizontal Integration predicts connected networks of cyber-physical systems, that introduce new levels of information, flexibility and operating efficiency. On the other hand, the Vertical Integration allows the interconnection of each level of supply chain. A company, that operates with a strong vertical integration, has a competitive advantage, because they are able to better respond to market demand changes or new opportunities.

Simulations consists in a digital tool able to assist production systems design. Their use is particularly relevant to optimize real time data from CPSs [30-37]. Cloud is a technology that allows both digital data storage and computing [6]. Such technology also enables “on-demand” data sharing among CPSs [38,39].

Advantages of Cloud computing include costs reduction and the possibility to support a more flexible business [40-49]. In fact, thanks to a digitalized environment, it is possible to manage and perform tasks in a more efficient way, protecting operating profits and cash flows [50-55].

Augmented Reality (AR) technology merges interactions among humans and CPSs, through the superimposition of digital data on reality [56].Such technology establishes a new human-machine interaction, through hi-tech systems ever more sophisticated and smarter.

Robots can be employed in several way within a smart factory. They are able to help humans for their tasks and can also interact with other robots, or “cobot” [57]. The adoption of such technology guarantees a greater productive efficiency and a reduction of errors, times and costs, as well as a greater safety for operators.

Additive manufacturing is the technology for the printing of physical objects. As source, they can directly use 3D CAD digital designs [58].
One of the most important advantage is the possibility to realize, through a single process, objects that, traditionally, are made of different parts. This technology is revolutionizing manufacturing, thanks to a continuous integration between computers, internet and manufacturing processes.
Cyber Security technology aims to protect shared information against cyber-attacks [59]. The best way to protect the company is the so called "security by design" model, that consists in implementing a system able to take into account security issues and based in a periodic assessment of choices made.

4. Results

We selected and analyzed a total of 68 articles present in literature from 2010 to 2020. Articles were summarized in a database and its analysis allowed a full descriptive analysis of the articles analyzed.
The analysis of journals highlighted how Journal of Loss Prevention In The Process Industries is the most present within database (7.4%) and that first 6 journals contain the 29,4% of articles (Table 6).
Figure 1 shows the temporal distribution of papers and, as it is possible to see, from 2017 there is a significant increase in number of publications. Figure 2 and Figure 3 show countries of origin and thematic areas of selected papers, respectively. China, with 34 articles, is the country with the largest number of papers (50% of the total), followed by USA (16 articles). Articles have been divided in "Empirical" and "Conceptual". Empirical studies include interviews, surveys and case studies, instead Conceptual ones are based on framework, reviews and models. In particular, we found 43 empirical and 25 conceptual articles. Most of the empirical articles are qualitative (41 articles on 43) and only 2 are quantitative (interviews). On the other hand, 17 conceptual articles are based on models' design and framework, instead the remaining 8 are reviews. Figure 4 shows the general classification of papers.

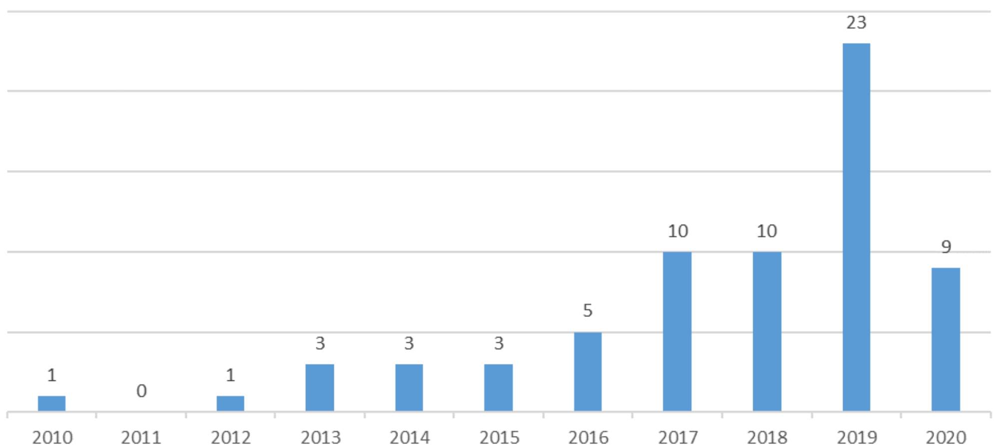

Figure 1. Temporal distribution of papers.

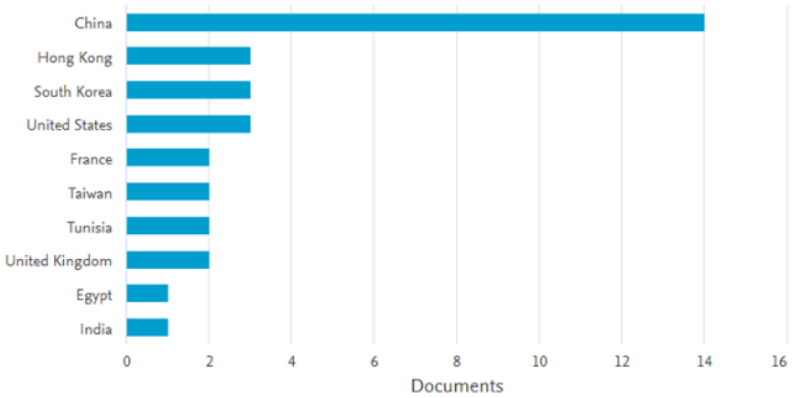

Figure 2. Countries of origin of selected articles.

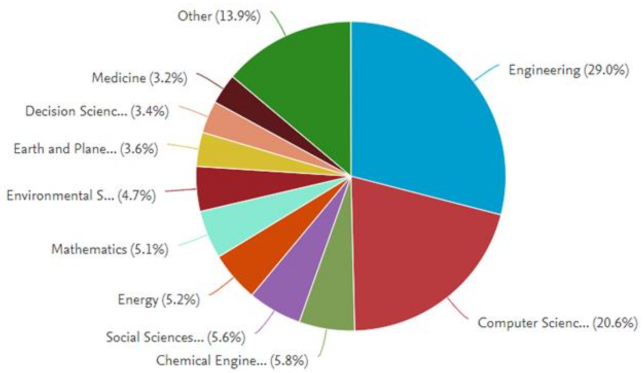

Figure 3. Thematic areas of selected articles.

Table 3. List of selected journals.

Journal	**n**	**%**
Journal Of Loss Prevention In The Process Industries	5	7,4%
Automation In Construction	3	4,4%
Journal Of Construction Engineering And Management	3	4,4%
Library Hi Tech	3	4,4%
Safety Science	3	4,4%
Sensors Switzerland	3	4,4%
Advances In Mechanical Engineering	2	2,9%
Applied Sciences Switzerland	2	2,9%
IEEE Access	2	2,9%
Industrial Management And Data Systems	2	2,9%
International Journal Of Online Engineering	2	2,9%
Process Safety Progress	2	2,9%
OTHERS	3	54,0%

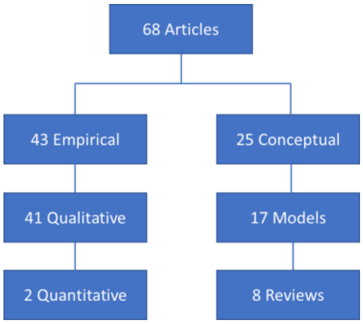

Figure 4. Classification of papers.

4.1. Content analysis: Technology for Safety Management.

By analyzing in detail the contents of the papers included in the database, it is possible to state how a large part deal with tools for the implementation of safety management principles [60-67].
For instance, in [68] an innovative and wearable IoT device is introduced , to integrate the ALI (Active Leading Indicators) system, able to identify and prevent hazard situations for operators. ALIs allow heart rate and body temperature monitoring and, when such values reach a critical threshold, operators are notified by the system. Results show the technical feasibility of the ALI system, that are also able to measure the human fatigue.
According to [13], safety instructions are fundamental in construction sites and they developed, through the use of GPS and cloud computing, a PSIM system able to provide personalized and real time instructions to operators depending on their physical characteristics and their position in the construction site. Results demonstrate how these systems involve several advantages, including the hazards reduction, the increase of operators' awareness of safety hazards and the efficient creation of a more safety environment as well.
Also, in the building sector, Zhang et al. (2019) developed a smart hard hat based on IoT and Cloud, including sensors, GPS receivers and infrared rays [47]. This system is able to reveal hazards and the possibility to act immediately [69-76].
During last years, several studies focused on advanced technologies for safety management purposes. In [77] the authors presented a system that integrate IoT, the "Wireless Sensor Network" (WSN) and the "Building Information Modeling" (BIM) that allows to make device able to detect and transmit data about environmental conditions, as well as to visualize the life cycle management of constructions. Such revolutionary technology allows to visualize and automatically remove any dangerous gases.
Among most used IoT devices, we found sensors. For example, in [78] a system with CMFM sensors for measuring CO levels in enclosed environments is introduced, with an alert time 3-7 times faster than conventional CO sensors. In other studies, sensors are used for safety purposes in warehouses [63,74,75, 79]. The network of wireless sensors is implemented to automatically collect environmental conditions and such information are managed and applied to design a model for measuring quality degradation. For example, through a Fuzzy logic, it is possible evaluate risk related to cold chain considering the health of operators [80]. A such monitoring system allows to manage products always with the desired conditions in terms of temperature, humidity and lighting intensity [68,77,80-87]. Results show how hazards in cold chain can be reduced, and it is possible increase, at the same time, both satisfaction of workers and the overall efficiency.
Graveto et al. (2019) introduce the "Shadow Security Unit" (SSU) that is a device based on similar technologies and able to detect any deviations comparing SCADA ("Supervisory Control and Data Acquisition") networks and physical input/output of a remote unit. More in details, such SSU is an economical device that allows to model a physic process and detect slight variations basing on Machine Learning. In this way, it is possible to control data flows through innovative monitoring approaches and to face security risks not otherwise detectable. This approach appears particularly suitable for workers in coal mines for real time monitoring of gases and locating operators.
In another group of the analyzed articles experimental applications of IoT and Cloud computing are developed [78,79,88-92]. For instance, in [74] the authors propose management techniques based on IoT and RFID able to

increase safety levels for warehouse and logistic, with the storage of products based on specific classes (pCBS). Issues related to safety of products, storage places, transports, environment and operators are managed through the use of smart methods such as RFID-IoT. For example, they are able to perform the minimization of paths and, at the same time, maximize safety levels during the path. Such system (RFID/IoT) is also discussed for managing underground buildings in China [18], basing on an alert system the prevent accidents and improve safety management. In particular, it integrates FBG sensors and a tracking RFID system.

BIM technology is often related to IoT and such combination is considered a powerful paradigm for improving both building processes and operating efficiency [13,14]. The authors identified different sectors for the application of such technology, including building and monitoring, health and safety management, as well as management of logistic and building and facilities. Finally, basing on some limitations, they also suggest important direction for future works, focusing on models oriented to SOA services and based on Web services for the integration of BIM and IoT.

5. Conclusion

In the present research, a systematic literature review was performed to understand what impacts Industry 4.0 enabling technologies have on safety management. In order to do this, we collect and analyze 68 papers published between 2010 and 2020. The temporal distribution of articles shows that there was a growing interest in this field since 2017. Empirical studies include interviews, surveys and case studies, instead conceptual ones are based on framework, reviews and models.

Several examples were presented to show how Industry 4.0 technologies can benefit safety management. In particular, the two most used enabling technologies for security management are Industrial Internet of Things and Clouds, whose use represents over 80% of the analyzed papers, through the use of smart devices, advanced monitoring systems and elaboration of digital information. The use of these technologies has important implications regarding the new skills necessary for safety management, compared to those of traditional professional figures.

We found that Industry 4.0 can increase safety levels in warehouse and logistic, with the storage of products based on specific classes. Furthermore, issues related to safety of products, storage places, transports, environment and operators can be managed through the use of smart methods using RFID-IoT technology. For example, it is possible to perform the minimization of paths and, at the same time, maximize safety levels during the path.

Finally, the building sector is one of the most debated sectors for the implementation of smart technologies to ensure high safety level. The future developments of this research consist in the stratification of the enabling technologies for safety management, for the different industrial sectors and in the development of a methodology to quantitatively evaluate their impacts.

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