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Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives

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ABSTRACT

Industry 4.0 and its other synonyms like Smart Manufacturing, Smart Production or Internet of Things, have been identified as major contributors in the context of digital and automated manufacturing environment. The term industry 4.0 comprises a variety of technologies to enable the development of the value chain resulting in reduced manufacturing lead times, and improved product quality and organizational performance. Industry 4.0 has attracted much attention in the recent literature, however there are very few systematic and extensive review of research that captures the dynamic nature of this topic. The rapidly growing interest from both academics and practitioners in Industry 4.0 has urged the need for review of up-to-date research and development to develop a new agenda. Selected 85 papers were classified in five research categories namely conceptual papers on Industry 4.0, human-machine interactions, machine-equipment interactions, technologies of Industry 4.0 and sustainability. The review primarily attempted to seek answers to the following two questions: (1) What are different research approaches used to study Industry 4.0? and (2) What is the current status of research in the domains of Industry 4.0?. We propose a sustainable Industry 4.0 framework based on the findings of the review with three critical components viz., Industry 4.0 technologies, process integration and sustainable outcomes. Finally, the scope of future research is discussed in detail.

1. Introduction

Industry 4.0 is a revolution in manufacturing, and it brings a whole new perspective to the industry on how manufacturing can collaborate with new technologies to get maximum output with minimum resource utilization. Industry 4.0 is a German project that has amalgamated manufacturing with information technology (Adolph et al., 2016). The outcome of this collaboration results in the development of factories that are "smart," i.e., they are highly efficient in resource utilization, and they adapt very quickly to meet management goals and current industry scenarios (Wittenberg, 2016). The information technology part of Industry 4.0 consists of a cyber-physical system (CPS), cloud computing, and the Internet of Things (IoT). It is the CPS that makes the whole factory adaptable (Ivanov et al., 2016; Wang et al., 2015a)). It is a system formed by the integration of physical systems; in the case of manufacturing, it is machines such as a CNC, lathe, mill, or grinder to a processing unit such as a computer (Karakose and Yetis, 2017; Monostori, 2014). In the system, the computer acts as the head and the machine acts as the body, i.e., as there are changes, the computer network takes the decision and implements it through the collection of the machine. The system also consists of a feedback loop: When there is any change in the input parameter, the output is changed to meet the alteration on input, so we can say that the feedback loop works as a two-way system. The system, due its high adaptability, is used in hospitals, traffic control systems, and power generation and distribution. The second part of this system is cloud computing, which in simple terms is the delivery of services related to the computer or information technology like a server, storage, or database on the internet. This is referred to as the cloud because it is not actually present where the service is being used, but at a remote location, and the whole system is controlled by a third party (Liu and Xu, 2017). The advantages that cloud computing gives are the economies of operation, the speed of service, the massive scale of operation, and accessibility, as it can be accessed in any part of the world, no matter how far away the cloud is located (Yu et al., 2017).

The third part of the system is the IoT, which refers to machine-to-machine interaction without human intervention (Xu et al., 2014). In the IoT, there is a network of devices where each device

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has a unique identification through the computer system to which it is connected. The devices connected to the system can be controlled remotely with high accuracy and efficiency. So, the IoT makes the system smart, and this is what has led to the industrial revolution known as Industry 4.0 (Lee et al., 2017b; Lu and Cecil, 2016).

There is growing interest around Industry 4.0, yet there is a scarcity of systematic, extensive reviews of the recent research on Industry 4.0 (Lu and Cecil, 2016). This paper seeks to explore the status of the research in domains of Industry 4.0. This paper identifies Industry 4.0 research categories based on a systematic literature review (SLR) viz., *conceptual papers on Industry 4.0, human-machine interactions, machine-equipment interactions, technologies of Industry 4.0*, and *sustainability*. The review was conducted with two research questions in mind: (1) What are the different research approaches used to study Industry 4.0? (2) What is the status of research in the domains of Industry 4.0? The review paper is structured as follows. Section 2 describes the review methodology used for the SLR. Section 3 presents the descriptive findings from the review. Section 4 presents the detailed review of the collected material. Section 5 describes the proposed sustainable Industry 4.0 framework based on the findings of the review. Section 6 provides the scope for future research. Section 7 concludes the review, presents the research contributions and research limitations.

2. Review methodology

A literature review is an essential part of any research work. Through literature review, the pertinent literature is assessed and analyzed, with an aim of finding possible research gaps. The research gaps should be such that, if worked upon, would help strengthen the field of study (Tranfield et al., 2003). Saunders et al. (2016) prescribed a structured literature review through an iterative cycle of defining suitable search keywords, searching the relevant literature, and performing the analysis at the end. In this paper, the authors adopted a similar review procedure.

For this paper, first, relevant sources of publication were identified regarding developments in the fields of Industry 4.0 and smart manufacturing. For this, the authors referred to papers from the Web of Science (WoS) database, which contains a significant number of renowned publications, like Emerald, Taylor and Francis, Springer, IEEE, and Elsevier. The structured review methodology adopted a six-step process as presented in Fig. 1 (Lamba and Singh, 2017; Arunachalam et al., 2017; Nguyen et al., 2017; Wamba et al., 2015; Mishra et al., 2016).

2.1. Selection of database

The search strategy was developed by first going through the relevant data sources. To have access to a wide range of academic and conference publications, the Web of Science database was selected. Web of Science is one of the most extensive abstract and citation databases and includes thousands of peer-reviewed journals in the fields of science, technology, medicine, and social sciences. These peer-reviewed journals belong to various publishing houses, including Elsevier, Springer, Emerald, Taylor and Francis, and IEEE.

2.2. Keyword selection

The authors cited only the most relevant and appropriate research publications related to the topic at hand to establish a reproducible, comprehensive, and unbiased article search process. The keywords used by the authors fell into the following two categories:

Industry 4.0–related keywords: *i) Industry 4.0, ii) Smart manufacturing, iii) Smart production, iv) Smart factory, v) Cyber-physical Systems, vi) Cloud Manufacturing, vii) Internet of Things (IoT)*

Operations-related keywords: *i) Production, ii) Manufacturing, iii) Just in Time, iv) Aggregate Planning, v) Capacity planning, vi) Lean manufacturing, vii) Quality, viii) Process improvement*

Search was executed through a pairwise query, taking one keyword from each category at a time.

2.3. Collection of articles

The initial search queries resulted in a total of 529 publications. The authors ensured that different aspects of Industry 4.0 were covered. Book chapters, books, doctoral theses, white papers, editorial notes, etc. were excluded from the search to ensure that the research originated from academic sources (Ramos et al., 2004; Lamba and Singh, 2017). The total number of articles dropped to 202.

2.4. Filtering (inclusion/exclusion)

To refine the results further, authors removed duplicates, papers that were present in more than one combination of keywords, and articles with incomplete bibliographic data points. Articles were also filtered based on their relevance to the topic. In addition, articles that mentioned Industry 4.0 as a short point of reference or as

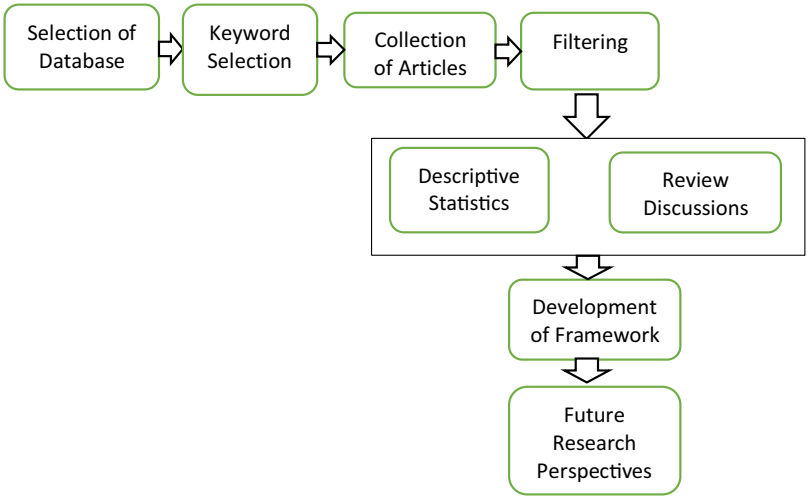

Fig. 1. Research process adopted for the structured literature review.