Enabling technologies, impacts and challenges of “Industry 4.0” in the manufacturing context: some insights from a preliminary literature review

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Abstract: The initiative of Industry 4.0 (I4.0) has been proposed in Germany in 2011. From that moment, both academical and industrial communities started to be interested in this new paradigm due to its potential capability of transforming traditional manufacturing systems into flexible, customizable and autonomous ones. Indeed, scholars have provided contributions aimed at developing a framework for Industry 4.0 related concepts such as smart factory, factory of the future (FoF) and cyber physical systems (CPS). Furthermore, the literature investigates vertical and horizontal integration enabled by Industry 4.0 enabling technologies, as well as their industrial practices. Nonetheless, a comprehensive understanding of the concept of Industry 4.0 evaluating the overall plethora of 14.0 enabling technologies has been addressed by very few studies in the literature. Moreover, the potential impacts as well as the challenges related to the application of Industry 4.0 are scattered in different studies. On that basis, this paper aims at presenting a state-of-art of industry 4.0 paradigm applied in the manufacturing context. In particular, this study focuses on identifying i) the 14.0 enabling technologies; ii) the achievable benefits and faced obstacles in adopting 14.0 paradigm and; iii) the human- and sustainability-related factors effected by Industry 4.0. This objective has been achieved based on the preliminary results of a literature review of 73 papers selected from Scopus and Web-of-Science databases. The (preliminary) results allowed to point out the main elements emerging from the sample analyzed, as well as their level of diffusion within the literature. Although various contributions have been written on Industry 4.0 area, the majority of them are focused on the impacts of digital enabling technologies in the domain of smart factory, stressing the topic of production scheduling and maintenance. Less attention has been paid on the improvement of product or service development and to the reconfiguration of the supply chain in the 14.0 era. This paper also shows that human and sustainability related aspects are less focused, but there is an increasing trend in recent years. Besides, even though the implementation of 14.0 enabling technologies in single business processes has been addressed by several works in the literature, utilization of combination of different technologies and a clear definition of what types of benefits they can bring out, is under-investigated.

Keywords: Industry 4.0, Literature review, Manufacturing

1. Introduction

The process of globalization, mass customization and competitive business environment showed that the “traditional” enterprise is facing new business challenges in today’s turbulent economy (Kamble et al., 2018; Simmert et al., 2018). The demand for shorter delivery time, more efficient and automated processes, higher quality and customized products have driven companies towards the so-called fourth industrial revolution, which is normally known as Industry 4.0 (I4.0). National initiatives such as Industrie 4.0 proposed by Germany in 2011, Smart Manufacturing by US in 2012, Made in China 2025 by China in 2015 and Impresa 4.0 by Italy in 2016 have all strengthened the importance and strategic position of future manufacturing (Drath and Horch, 2014; Xu et al., 2018; Zheng et al., 2018). Several efforts have been put by scholars on this topic, attempting to clarify the conceptual constituents and domains of application. As regards 14.0 enabling technologies, the literature pinpoints the main founding technology in the Internet of Things (IoT) as the main enabler of cyber-physical systems (CPS) (Trappey et al., 2016). However, also other digital technologies might be considered as enabler of this new paradigm. Some examples are additive manufacturing (Chen and Lin, 2017), Big Data and Analytics (Xu and Duan, 2019) and Cloud computing (Urbina Coronado et al., 2018). Moreover there are contributions showing the main impacts of the implementation of 14.0 principles on factors related to employees’ working conditions and skills (Kazancoglu and Ozkan-Ozen, 2018; Stock et al., 2018) as well as sustainability and circular economy (Bressanelli et al., 2018). The literature presents scattered studies concerning the above-mentioned issues, but a comprehensive understanding of Industry 4.0 regarding these aspects is missing (Piccarozzi et al., 2018; Schneider, 2018). Thus, the authors want to make their contributions to fill this gap by showing the preliminary results of a literature review. The paper is divided into four sections, section 2 introduces the 14.0 background and motivation of this paper, section 3 describes the adopted methodology for literature review, section 4 demonstrates the main findings...
and results, and section 5 summarizes the paper with conclusions and future directions.

2. Research background and gaps

2.1 Industry 4.0 phenomenon

Industry 4.0, firstly has been proposed in Hannover Fair (Germany) in 2011 (Drath and Horch, 2014). It can enable the creation of network resources and services connecting the internal value chain of companies and enhancing flexibility and competitiveness (Xu, 2017). In particular, Industry 4.0 is composed by the fusion of physical and virtual world, where CPS plays the core role of connecting these components, utilizing sensors, actuators and its computation power, transmitting the real-time data through industrial network, and providing feedback for decentralized decision making (Hermann et al., 2016; Kagermann et al., 2013). Similar concept is Internet of Things (IoT), which has the similar architecture, while holding a lower combination of computational elements (Rad et al., 2015). Other principles proposed by (Hermann et al., 2016) are technical assistance, information transparency and decentralized decisions. Moreover, the concept of Industry 4.0 is enriched by combination of further Information Technologies (IT) and Operational Technologies (OT) to facilitate the connection among humans, machines and products in an intelligent way, for the purpose of satisfying customized demands (Beckmann et al., 2016; Chen, 2017; Zhou et al., 2016). Chen and Lin (2017) explored the technical and managerial challenges of Additive manufacturing implementation in manufacturing context, while Xu and Duan (2019) attempted to connect big data with CPS with the aim of improving system scalability, security and efficiency. In addition, Urbina Coronado et al. (2018) made the efforts of providing easily implementable Manufacturing Execution System (MES) enabled by cloud computing. That demonstrates that Industry 4.0 may concerns the adoption of several different technologies. However, considering 4.0 as only a technological revolution, can’t cope with all the issues faced by companies, who require not only the competencies of knowing and utilizing digital technologies, but also the competencies to manage them in a smart and sustainably way. Business and engineering processes have to be integrated flexibly, efficiently and with constantly high quality and low cost (Wang et al., 2016). Kazancoglu and Ozkan-Ozen (2018) has presented a structural competency model to cope with the personnel competency gap in Industry 4.0 environment, while Bressanelli et al., 2018 have extended the implementation of Industry 4.0 technology into the domain of circular economy.

2.2 Research gap and questions

Scholars have put a lot of efforts in the technological domain of Industry 4.0, attempting to understand the feasible and potential applications of IT and OT. Several efforts have also been put in personnel competencies in future manufacturing environment, as well as the sustainability impact by digital technologies. However, a systemic analysis considering different impact areas of Industry 4.0 is still missing; therefore, this paper is aimed at filling this research gap by conducting a literature review in order to understand: 1) the 4.0 enabling technologies; 2) the achievable benefits and faced obstacles in adopting 4.0 paradigm and 3) the impacts of 4.0 on human factors and sustainability aspects. In this paper we present the preliminary results of our research.

3. Methodology

3.1 Literature selection process

In this section, we present the approach that we have adopted for selecting 14.0 related literatures. The selection process is composed by four phases, for each phase, specific criterions have been used in order to include related papers and exclude unrelated ones. In pre-selection phase, we started by searching “industry* 4.0” as keyword in article title, abstract, key words in Scopus and Web of Science (WoS) databases. The starting total number of papers was 6169, 3903 from Scopus and 2266 from WoS. Table 1 and Table 2 show separately the criterions that we have used, and number of papers remained during pre-selection process in Scopus and WoS database selection, in which 5 elimination and selection criterions have been implemented, leading to 1558 papers remained.

Table 1: Pre-selection process in Scopus

<table>
<thead>
<tr>
<th>Elimination/Selection Criteria</th>
<th>Total number</th>
<th>Papers eliminated</th>
<th>Papers remained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper is NOT in English</td>
<td>3903</td>
<td>343</td>
<td>3560</td>
</tr>
<tr>
<td>Document type IS: article, article in press, review</td>
<td>3560</td>
<td>2445</td>
<td>1115</td>
</tr>
<tr>
<td>Subject area is NOT: engineering; computer science; business; management and accounting; social science; decision science</td>
<td>1115</td>
<td>72</td>
<td>1043</td>
</tr>
<tr>
<td>Year &gt; 2011</td>
<td>1043</td>
<td>0</td>
<td>1043</td>
</tr>
</tbody>
</table>

Table 2: Pre-selection process in WoS

<table>
<thead>
<tr>
<th>Elimination/Selection criteria</th>
<th>Total number</th>
<th>Papers eliminated</th>
<th>Papers remained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper is NOT in English</td>
<td>2266</td>
<td>218</td>
<td>2048</td>
</tr>
<tr>
<td>Document type IS: article, review</td>
<td>2048</td>
<td>1324</td>
<td>724</td>
</tr>
<tr>
<td>Research area IS: engineering; computer science; business economics; automation control system; operation research management science; science technology other topics; robotics; social science other topics; sociology; mechanics;</td>
<td>724</td>
<td>112</td>
<td>612</td>
</tr>
<tr>
<td>Web of science category IS: engineering manufacturing;</td>
<td>612</td>
<td>97</td>
<td>515</td>
</tr>
</tbody>
</table>
In the second phase of paper selection, we combined the pre-selected papers from Scopus and WoS together, implementing a series of common Exclusion Criteria (EC) for paper selection. In this phase, we exclude 1149 papers from 1558 papers, which results in a remain of 409 papers. A detailed selection process is shown in Table 3.

### Table 3: Second phase selection process

<table>
<thead>
<tr>
<th>Common Exclusion Criterion (EC)</th>
<th>Total number</th>
<th>Number of paper eliminated</th>
<th>Total number remained</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC1 Duplicates elimination (same DOI)</td>
<td>1558</td>
<td>515</td>
<td>1043</td>
</tr>
<tr>
<td>EC2 Conference paper elimination</td>
<td>1043</td>
<td>76</td>
<td>967</td>
</tr>
<tr>
<td>EC3 Journal title is NOT in English</td>
<td>967</td>
<td>83</td>
<td>884</td>
</tr>
<tr>
<td>EC4 Elimination of Journal with No Impact Factor (IF)</td>
<td>884</td>
<td>429</td>
<td>455</td>
</tr>
<tr>
<td>EC5 Elimination of conference proceedings</td>
<td>455</td>
<td>7</td>
<td>448</td>
</tr>
<tr>
<td>EC6 Elimination of Journal with IF&lt;1</td>
<td>448</td>
<td>39</td>
<td>409</td>
</tr>
</tbody>
</table>

The two selection phases have brought to 409 articles available for further analysis. In order to achieve our research objectives, we carried out a further selection phase, which provided for reading titles and abstracts in order to exclude the ones who are not in our research scope and the ones that are too technical. As a result, 80 articles have been considered “not in scope” class, while 82 papers were classified as “too technical”. Therefore, by conducting this third phase preliminary reading process, the final sample was characterized by 247 papers. Since our target is to provide a preliminary study, in this paper we concentrate on the results achieved from the reading of 73 selected papers.

### 3.2 Sample description

#### 3.2.1 Year wise publications

In order to have a general view of the piece of literature that we have been analysing, a primary mapping based on year wise publication number has been conducted. Figure 1 shows an increasing trend of the number of published papers per year concerning Industry 4.0 in manufacturing context, from 2016 to 2018. It implies that Industry 4.0 is attracting more and more attention from academic community, and higher quality articles has started to be accepted in high quality journals. We also found that no significant contributions have been published before 2016. This trend can be explained by the fact that Industry 4.0 itself is a relative novel topic in operations management domain. Moreover, the paradigm was born in Germany in 2011 and first contributions were published in Conferences proceedings, generally in German language.

Our literature selection criterion excludes papers published through conferences; therefore, it is reasonable to say that, due to the novelty of the topic and our selection criterion, the number of papers published in peer view journals emerge mainly in 2016 and following years.

#### 3.2.2 Journal contributions on Industry 4.0 topic

Figure 2 lists the journals where the selected 73 selected articles have been published. International Journal of Production Research (IJPR), International Journal of Advanced Manufacturing Technology (IJAMT) and Process Safety and Environmental Protection (PSEP) are the top three journals where 14.0 related articles are published. IJPR is ranked as first and this is probably due to the fact that it is focused on manufacturing/production. Since 14.0 is enabled by advanced manufacturing technologies, including Operation Technology (OT) and Information Technology (IT), it is normal to see some articles published on IJAMT. Besides, it is interesting to notice that 8 articles are published through PSEP, indicating that 14.0 could have also impact on safety and environment, which implies its potentiality on sustainability. That supports our scope addressing the identification of impacts by Industry 4.0 regarding human and sustainability factors.
expected, “Industry 4.0” ranks first, “Cyber-Physical Systems” (CPS) is in second place and then “Internet of Things” (IoT) in third one. The connection among each keyword represents the co-occurrence of them. Thus, the closer the distance of keywords, the higher probability that they are present together in the paper.

4. Content analysis result

In order to provide more insights about the contributions of the articles of the sample and answer to the research questions achieving our objectives, in the following sections we will show the content analysis results.

4.1 I4.0 enabling technologies

Figure 6 lists all the technologies investigated in the literatures which can be considered as enabling technologies of Industry 4.0. Among them, Internet of Things (IoT), Big data & Analytics, Cloud Computing, Cyber Physical System (CPS), Smart sensors are ranked in top five. It is interesting to notice that these five technologies are all computing-related technologies and, according to several contribution in the literature, they are the foundations of I4.0. However, 14.0 is not limited to these single technologies, but it concerns the connection of several elements (assets, devices, humans) in order to collect data from them, utilizing computing power to make advanced analytics, and thus accelerating the decision-making process (Hermann et al., 2016). From Figure 7, we also see that, there is a huge diversity and richness of technologies being investigated for I4.0, covering the Digital connection group (CPS, Sensors, IoT, Identification technology, Industrial communication network, M2M, Mobile computing, Semantic technologies), Information processing group (Cloud computing, Big data & Analytics, Cyber security), Intelligent manufacturing group (Additive manufacturing, Simulation, Collaborative robotics, Digital twin, Virtual manufacturing, CIM, Industrial wearable systems, Augmented & Virtual Reality), and that of Autonomous decision making group (Artificial Intelligence, Enterprise & Business intelligence).
literature. “Internal management challenges” is mainly related to the lack of expertise and competencies as well as culture for 4.0. At the same time, the cluster “Technological challenges” includes big data management, cyber security issue, technology maturity & standardization, system reliability. Finally, “Scientific challenges” are the ones concerning lack of theory or field validation and “External challenges” concern missing government support or no interest by customer and market.

4.2 Benefits and challenges of I4.0

Through categorizing the benefits into macro categories as shown in Figure 11, “Quality improvement” is the most perceived benefits brought by I4.0, followed by “Reduction of cost” and “Flexibility improvement”. According to our classification criterion, “Quality improvement” includes aspects such as process transparency improvement, traceability, accuracy, reliability, timeliness and customer satisfaction. “Cost reduction” focuses on decreasing operations and energy cost in the whole value chain. “Flexibility improvement” indicates a more agile and quick capability. It is possible to state that I4.0 has the important function of increasing competitiveness through improving quality. Another interesting result is the emergence of the “Culture” factor, which is related to workforce motivation. This aspect shows that implementing I4.0 allows to provide not only traditional benefits related to products and processes, but also the human-beings, which constitutes the soft part of the 4.0 transformation.

4.3 I4.0 human and sustainability related factor

4.3.1 I4.0 human related factors

Through literature reviewing process, we figured out not only technological aspects of 4.0, but also human-related aspect. We have identified five specific categories as shown in Figure 9, which are “work content”, “skills/competencies”, “Ergonomics/safety”, “Student education” and “Employee training”. “Work content” refers to those literatures who investigate reconfiguration of existing work content and how the future of work will be. Then “skills/competencies” groups all the debates concerning the required skills and competences by companies which are implementing the principles of the 4.0 paradigm. “Ergonomic/safety” concerns issues related to ergonomics and safety faced and related solutions enabled by the 4.0 paradigm. “Student education” and “employee training” refer to 4.0 related training issues. We found out that there is an increase interest of these topics in the literature especially for issues concerning future work content design, skills/competencies and employee training. That is aligned to the fact that I4.0 is not only a matter of technology, but also employees play a very important role for a successful implementation. Furthermore, the reason why of the link between different human factors and technical factors lies in the fact that digital technologies are replacing the old ones, thus new competences are required. Therefore, that leads to the need for the reconfiguration of future work content, and consequently, make training employee and educating students a strategic factor.
4.3.2 I4.0 sustainability related factors
An attempt of exploring how literatures concern for sustainability has been also conducted. The results show that economical sustainability is ranked in the top place, implying that I4.0 is still mainly considered as economic engine. However, we can still find that a group of contributions started to talk about the impact of I4.0 on process safety, environmental protection, social sustainability and circular economy perspectives. Similar to the human-related factors, we detected that there is an increase trend in interest in these topics. Although economical sustainability still attracts the most attention, we cannot neglect that “Process safety & environmental protection (PSEP)” and “Social sustainability” are being more involved in I4.0 discussion. Results are shown in Figure 10.

5. Discussions and conclusions
In this paper, we have conducted a literature review for Industry 4.0, following a rigorous procedure for paper selection, describing statistically the selected sample, and answering 3 research questions. The objective of this study is twofold: on the one hand the identification of I4.0 enabling digital technologies, on the other hand the analysis of the main impacts of I4.0 implementation concerning benefits, human- and sustainability-related factors. Finally, the paper focuses on the main obstacles that companies can face adopting I4.0 paradigm. The descriptive analysis firstly shows an increasing trend in the number of I4.0 topic-related published papers in peer-review journals, confirming the increasing interest and attractiveness of I4.0 issues (Liao et al., 2017). In fact, the selected papers are all published since 2016. The content-analysis in section 4 have tried to answer the 3 research questions. We mapped all I4.0 enabling technologies emerging by the literature review carried out. The fact that IoT, Big data & analytics, Cloud computing, CPS are the most considered enabling technologies in the literature, confirms that they are the founding principles of I4.0 (Hermann et al., 2016). In addition, human-related and sustainability-related aspects impacted by I4.0 adoption are shown; we highlighted that the number of papers investigating such aspects are little, but there is an increase trend. Finally, I4.0 benefits and challenges are summarized; according to the results of our preliminary analysis, quality improvement is the most important benefit of I4.0, meanwhile, internal management challenges and technical challenges are the biggest challenges. This paper has some limitations. Since the paper is a literature review with preliminary analysis, the number of selected papers is limited. An extension of analysed papers should be further considered. A more complete analysis will also help providing a roadmap for I4.0 research; this objective will be achieved by analysing the remaining papers to be considered in our study.

References


