OPEN ACCESS
The Journal of Engineering and Exact Sciences – jCEC, Vol. 08 N. 11 (2022)
journal homepage: https://periodicos.ufv.br/jcec
eISSN: 2527-1075
ISSN: 2446-9416

Impacts and challenges of industry 4.0 in manufacturing: a systematic literature review

Impactos e desafios da indústria 4.0 na manufatura: Uma revisão sistemática da literatura

Article Info:
Article history: Received 2022-06-01 / Accepted 2022-11-20 / Available online 2022-12-12
doi: 10.18540/jcecvl8iss11pp16294-01e

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Abstract

The concept of Industry 4.0 emerged in Germany as a strategy for innovation and recovery of economic performance and has spread worldwide. The digital transformation proposed by Industry 4.0 is driven by intelligent manufacturing processes, digitalization, flexibility, integration of systems, and real-time analysis of big data generating intelligent processes and services oriented to customer needs. However, despite the opportunities produced by technological innovation, the fourth industrial revolution has established an environment of uncertainty in the labor market and business models reflected throughout the social sphere. Thus, this study aimed to identify the potential impacts and challenges of Industry 4.0 through a systematic literature review (SLR). Our findings pointed to seven potential impacts of Industry 4.0 on manufacturing: (i) environmental, (ii) competitive, (iii) economic, (iv) education, (v) labor market, (vi) business models, and (vii) social. Additionally, six potential challenges faced by manufacturing in adopting digital transformation were found: (i) management, (ii) government, (iii) implementation, (iv) workforce, (v) operation, and (vi) security. The results indicated that accurate understanding of the concepts and scope of Industry 4.0 are under construction and that knowledge sharing will be decisive in shaping the future of the transition from current business models to smart manufacturing.
Keywords: Industry 4.0. Transformation industry. Manufacturing. Systematic Literature Review.

Resumo

O conceito de Indústria 4.0 surgiu na Alemanha como uma estratégia para inovação e recuperação do desempenho econômico e se espalhou pelo mundo. A transformação digital proposta pela Indústria 4.0 é impulsionada por processos de manufatura inteligente, digitalização, flexibilidade, integração de sistemas e análise em tempo real de big data, gerando processos inteligentes e serviços orientados às necessidades dos clientes. No entanto, apesar das oportunidades geradas pela inovação

tecnológica, a quarta revolução industrial estabeleceu um ambiente de incerteza no mercado de trabalho e modelos de negócios, refletindo-se em toda a esfera social. Assim, este estudo teve como objetivo identificar os potenciais impactos e desafios da Indústria 4.0 por meio de uma revisão sistemática da literatura (RSL). Nossos achados apontaram sete potenciais impactos da Indústria 4.0 na manufatura: (i) ambiental, (ii) competitivo, (iii) econômico, (iv) educacional, (v) mercado de trabalho, (vi) modelos de negócios e (vii) social. Além disso, foram encontrados seis desafios potenciais enfrentados pela manufatura ao adotar a transformação digital: (i) gestão, (ii) governo, (iii) implementação, (iv) força de trabalho, (v) operação e (vi) segurança. Os resultados indicaram que a compreensão precisa dos conceitos e do escopo da Indústria 4.0 está em construção e que o compartilhamento de conhecimento será decisivo na moldagem do futuro da transição dos modelos de negócios atuais para a manufatura inteligente.
Palavras-chave: Indústria 4.0. Transformação industrial. Manufatura. Revisão Sistemática da Literatura.

1. Introduction

In recent years, innovation and competitiveness have guided the transformations in manufacturing processes (Zheng *et al*., 2019). The digital transformation, promoted by the adoption of disruptive technologies, brings to the manufacturing environment the concept of smart manufacturing to innovate processes, business models, and create new sources of value, thereby characterizing the fourth industrial revolution (i.e., Industry 4.0), a term coined in 2011 by Klaus Schwab, the founder and president of the World Economic Forum (Schwab and Davis, 2018; Xu *et al*., 2018).

The first industrial revolution occurred between 1760 and 1840 and was marked by the invention of the steam engine, initiating mechanical production. In the late 19th century, the second industrial revolution changed production processes by introducing electricity and assembly lines, characterizing mass production (Sang-Chul, 2018). The third industrial revolution took place in the 1960s and is known as the digital revolution, as it was marked by the advent of the computer, mainframe computing, personal computers, and the internet (Xu *et al*., 2018).

The fourth industrial revolution presents the concept of smart factories capable of creating a world where physical and virtual manufacturing systems can cooperate globally and flexibly (Schwab, 2016). Nonetheless, the scope of Industry 4.0 is not restricted to connected intelligent systems and machines, and it distinguishes itself from previous revolutions by promoting the fusion of technologies and interaction capable of linking the physical, digital, and biological worlds (Schwab, 2016; Frank *et al*., 2019).

The technologies for monitoring real-time production data, virtualization, data analytics, big data, robotics, simulations of manufacturing operations, vertical and horizontal integration systems, the internet of things, cyber security, cloud computing, additive manufacturing, and augmented reality are the foundations of Industry 4.0 (Almeida, 2019; Pereira and Romero, 2017; Jabbour *et al*., 2018).

In manufacturing, the lack of knowledge and a comprehensive view of the challenges, impacts, and resources required for implementation creates barriers to adopting Industry 4.0 concepts and technologies (Shi *et al*., 2020). However, the breadth and intensity of this revolution will unfold changes that go beyond the factory floor, extending to the economic, social, and cultural sectors with implications that are still uncertain (Schwab, 2016).

The impacts and challenges of the fourth industrial revolution are relevant for a comprehensive understanding of the extent of digital transformation in society. As companies and economies adopt the technologies arising from Industry 4.0, the risk that emerging and developing economies are left behind due to lack of investments, professional qualification, and technological capacity becomes imminent (Schwab and Davis, 2018), thus emphasizing the importance of better understanding the meaning of digital transformation, its possibilities, as well as its impacts and challenges for emerging economies, including Brazil.

Building knowledge on the fourth industrial revolution is growing in the literature that has systematic reviews targeting the clothing industry (Lakmali *et al*., 2020), healthcare (Ilangakoo *et al*., 2019), energy systems (Nolting *et al*., 2019), logistics (Edirisuriva *et al*., 2019), supply chain (Rasanjanani *et al*., 2019), information science (Capinzaiki *et al*. 2019), manufacturing systems technologies (Alcácer and Cruz-Machado, 2019), Industry 4.0 maturity models (Elibal and Özceylan, 2020), among others, as well as scientific research directed at innovation ecosystems (Benitez *et al*., 2020), the prospects for innovative business models (FRANK *et al*., 2019), Industry 4.0 technologies (Xu *et al*., 2018; Aceto *et al*., 2019; Massood and Egger, 2019), and applications of Industry 4.0 technologies (Kumar *et al*., 2020). In short, the literature has studies of Industry 4.0 perspectives, trends, opportunities, and challenges, focusing mainly on the types and applications of its technological resources. Regarding the challenges and impacts of Industry 4.0 in manufacturing, generally speaking, the literature presents several limitations.

Considering the relevance of knowledge dissemination about the transforming intensity of Industry 4.0 in society, this study aimed to conduct a systematic literature review (SLR) based on articles published in journals up to the year 2020 that addressed the potential impacts and challenges of Industry 4.0 in manufacturing. The study is justified by the high volume of scientific publications found on Industry 4.0. Thus, conducting an SLR enables the presentation of an overview and updated scientific production, identifying, consistently, the current directions and gaps on the theme.

For the proposed objective to be achieved, the SLR was guided by a research protocol, complying with the methodological rigor that an SLR requires in order to map and analyze relevant studies based on the protocols proposed by Tranfield, Denyer, and Smart (2003) and Kitchenham (2007). Hence, the research questions that guided this study were as follows: (i) What are the potential impacts of Industry 4.0 manufacturing? (ii) What are the potential challenges resulting from the digital transformation for manufacturing? (iii) Which countries and journals are responsible for the publications? (iv) Is there a temporal evolution in the number of publications on the topic? (v) Which contexts have directed the published studies?

The originality of this study lies in its focus on the potential impacts and challenges of the fourth industrial revolution and presenting the state of the art regarding the implications of Industry 4.0 in manufacturing. The main contributions of this study to the research field are: (i) the presentation of the impacts of Industry 4.0 on manufacturing, providing the point of view of the extension of the digital transformation in manufacturing and consequently in society, and (ii) synthesis of the main challenges brought by Industry 4.0 to manufacturing and its characterization according to the current state of the art, providing theoretical support to develop guidelines capable of minimizing its extension in manufacturing, in addition to disseminating knowledge on the subject.

The remainder of the paper is organized as follows. In Section 2, the methodology is presented, with details of the research protocol, criteria for extracting and selecting the studies, as well as the computational resources used. Section 3 presents a bibliometric analysis containing the report of the temporal evolution of the publications, while section 4 presents the results and discussions. Lastly, Section 5 provides the conclusions and suggestions for future research are presented.

2. Methodology

The SLR was based on the protocols proposed by Tranfield *et al*. (2003) and Kitchenham (2007). The planning stage begins by identifying the research need and specifying the question(s) and objective(s) discussed in the introduction. The second stage consists of conducting the search comprising the selection of search engines, extraction, selection, and evaluation of the studies.

The concept of Industry 4.0 emerged from the impacts of information technology and digital transformation in manufacturing, although its dissemination poses challenges and opportunities to all societies and the economic sector or not (Schwab, 2016; Schwab and Davis 2018). In this way, the studies were selected according to multidisciplinary bases, as well as bases covering the field of engineering. The databases defined to extract the studies were IEE Xplore, Scopus, and Web of Science; as a quality standard, the databases have the peer review system as a criterion for indexing.

The studies were selected on the databases according to the following inclusion criteria: (i) articles published in journals, (ii) articles in English, and (iii) articles published up to 2020. Thus, any other type of publication (books, conference, editorial, among others) and articles in languages other than English were excluded. Table I shows the search strings used in the databases to extract the studies.

The Boolean operators AND and OR were used to construct the search strings, with which advanced searches were performed in the databases. The search fields varied from one database to another, making it necessary to analyze the search results for them to be as close as possible in terms of the content present in the results.

Table 1 - Search strings used to extract the studies

Databases	Search strings
IEEE Xplore	("Abstract":"Industr* 4.0") OR ("Abstract":"Fourth industrial revolution") AND ("Full Text & Metadata":Challenge*) OR ("Full Text & Metadata":Impact*) AND ("Abstract":"Transformation industr*") OR ("Abstract":"Industrial segment") OR ("Abstract":"Manufacturing sector") OR ("Abstract":"Manufacturing industries") AND ("Abstract":Manufacturing)
Scopus	TITLE-ABS-KEY (("Industr* 4.0" OR "Fourth industrial revolution") AND ((challenge*) OR (impact*)) AND ("Transformation industr*" OR "Industrial segment" OR "Manufacturing sector" OR "Manufacturing industries" OR Manufacturing))
Web of Science	TS=(("Industr* 4.0" OR "Fourth industrial revolution") AND ((Challenge*) OR (Impact*)) AND ("Transformation industr*" OR "Industrial segment" OR "Manufacturing sector" OR "Manufacturing industries" OR Manufacturing))

The process of extracting and selecting the studies for full text and quality analysis is shown in Figure 1. A total of 1632 articles were found in the databases; 776 of these documents were duplicates. After eliminating the duplicates, 856 articles remained for selection according to the reading of the title and abstracts. After reading the title and abstracts of the articles, 669 were rejected for lack of affinity with the established research objectives. Thus, 187 remained that, based on the reading of the abstracts and titles, suggested an affinity with the research objectives and, therefore, were selected for the reading of the full text. Then, the information that makes up this study was extracted from 52 articles.

The data synthesis performed in the third stage initially presents a bibliometric analysis containing a report on the temporal evolution of the publications. Next, results and discussions about the potential impacts and challenges of Industry 4.0 in manufacturing, which were identified in the selected studies, are presented. The computational resources used to develop the SLR were Microsoft Excel spreadsheets and the R Studio 3.6.3, StART 3.4, and VOSviewer 1.6.15 software.

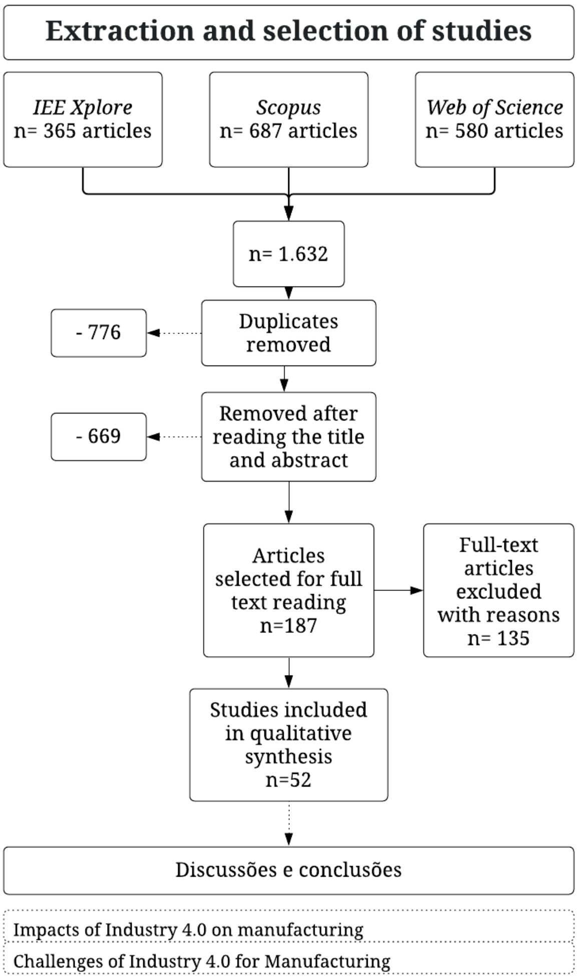

Figure 1 - Methodological Process of the Systematic Literature Review (Own representation, 2020)

3. Results and discussions

The following are the analyses and discussions concerning the SLR on the impacts and challenges of Industry 4.0 in manufacturing.

3.1 Impacts of industry 4.0 on manufacturing

As the concepts, functionalities, and applicability of disruptive technologies and other features of Industry 4.0 become widespread, the possible effects of digital transformation begin to be outlined. Klaus Schwab (2016), the creator of the concept Industry 4.0, identified five types of impacts of digital transformation: (i) economy, (ii) business, (iii) national and global, (iv) society, and (v) individual.

The first refers to economic growth, productivity, employment, labor substitution, and skills. The second discusses the reinvention of business models due to customer expectations, increased product quality, business collaboration, and transition from operational to digital models. When referring to the national and global impact, Schwab (2016) reported the need for the government to create rules so that competitiveness, fairness, inclusive intellectual property, as well as security and reliability, are fairly maintained, nationally and internationally. The impact on society underlines the concern with spreading scientific and technological advances without increasing social inequalities. Meanwhile, the individual impact covers how digital transformation affects privacy issues, notions of property, consumption patterns, time dedicated to work and leisure, and professional trajectory and competencies.

The impacts of implementing Industry 4.0 in European manufacturing, according to Felsberger *et al*. (2020), are divided into social, environmental, operational, and economical. Pereira and Romero (2017) divided the implications of the Industry 4.0 concept into industry, products and services, economy, work environment, and skills development. The analysis of the selected studies enabled us to divide the potential impacts of the transformation industry on manufacturing into environmental, competitiveness, economic, education labor market, business model, and social (Table 2).

The environmental impacts divided into waste reduction and energy consumption reflect the pros and cons of using technological resources in terms of consumption and manufacturing. Industry 4.0 revolutionizes manufacturing through interconnectivity. However, a high number of interconnected devices and massive data transmission significantly impact energy consumption (Humayun *et al*., 2020), increasing CO^2 emissions (Felsberger *et al*., 2020). Fossil fuel extraction and combustion for energy generation result in adverse health, environmental, and economic impacts. Nonetheless, advances in knowledge and technology make it possible to use more sustainable energy sources. As for manufacturing processes, Industry 4.0 technologies can positively impact waste generation by promoting the efficiency of material resources (Felsberger *et al*., 2020).

The massive use of technological resources for smart manufacturing promotes increased global competition for product quality and production costs (Fatorachian and Kazemi, 2018), promoting business opportunities, value creation through innovation, quality improvement, and meeting customer expectations that tend to increase complexity (Jie *et al*., 2020; Sorooshian and Panigrahi, 2020).

New market requirements and smart product manufacturing result in economic impacts influenced by emerging technologies that will drive innovation, playing a critical role in productivity and competitiveness (Pereira and Romero, 2017). Increased productivity enables inefficient practices to be eliminated, reducing costs, and improving revenue growth (Hartmann and Hattingh, 2018; Jie *et al*., 2020). Moreover, adopting highly technological resources in manufacturing will impact employee skills and abilities, automation will replace human effort, and new job openings will be created for skilled labor, consequently raising the salary range due to worker specialization (Jie *et al*., 2020; Sorooshian and Panigrahi, 2020).

Changes in the future labor market reconfigure skill development and training, significantly influencing the mechanisms by which the workforce is delivered to the market (Ling *et al.*, 2020). Thus, developing technical skills and social skills provided by the education and training system demand the modernization of educational institutions' teaching and learning programs, facilities, and infrastructure (Jagannathan *et al*., 2019; Mian *et al*., 2020).

In the labor market, successfully implementing digital transformation will depend on the workforce, which will have to adapt to technological, integrated, and connected systems, thereby requiring specific skills and competencies (Erro-Garcés, 2019; Kamblea *et al*., 2018; Pinzone *et al*., 2018). Cyber-physical systems, the internet, and other technologies coming from intelligent systems will change the human-machine interaction, replacing the human workforce in low-complexity, repetitive, and monotonous jobs with technological innovations (Sorooshian and Panigrahi, 2020; Kumar *et al*., 2020). The management of industrial systems with a high technological degree will also impact ergonomic factors, implying the need for industrial designs in intelligent manufacturing and human-centered environment (Sgarbossa *et al*., 2020)

Table 2 – Potential impacts of Industry 4.0 on manufacturing.

Impact	Characteristics	Authors
Environmental	Energy consumption	Humayun *et al*. (2020); Felsberger *et al*. (2020)
	Waste reduction	Felsberger *et al*. (2020)
Competitiveness	Production costs	Fatorachian; Kazemi (2018); Sorooshian; Panigrahi (2020)
	Innovation	Pereira; Romero (2017); Fatorachian; Kazemi (2018); Felsberger *et al*. (2020); Jie *et al*. (2020); Sorooshian; Panigrahi (2020)
	New business models and new competitors	Contador *et al*. (2020)
Economic	Increased productivity	Hartmann; Hattingh (2018); Felsberger *et al*. (2020); Jie *et al*. (2020); Rojko *et al*. (2020); Sorooshian; Panigrahi (2020)
	Revenue growth	Pereira; Romero (2017); Hartmann; Hattingh (2018); Mittal *et al*. (2018); Jie *et al*. (2020); Sorooshian; Panigrahi (2020)
	Job creation - Specialisation	Hartmann; Hattingh (2018); Rojko *et al*. (2020)
	Cost reduction	Felsberger *et al*. (2020); Jie *et al*. (2020)
	High wages - Specialization	Sorooshian; Panigrahi (2020)
Education	Adaptation of the teaching structure	Hartmann; Hattingh (2018); Ing *et al*. (2019); Jagannathan *et al*. (2019); Herceg *et al*. (2020); Mian *et al*. (2020)
	Growth in education levels	Jung (2019); Rojko *et al*. (2020)
	Training and talent development	Ling *et al*. (2020)
Job market	Ergonomics	Sgarbossa *et al*. (2020)
	New skills and abilities of the workforce	Pereira; Romero (2017); Kamblea *et al*. (2018); Pinzone *et al*. (2018); Erro-Garcés (2019); Jagannathan *et al*. (2019); Jerman *et al*. (2019); Ling *et al*. (2020); Raj *et al*. (2020); Stentoft *et al*. (2020)
	Human substitution for technological innovations	Kumar *et al*. (2020); Sorooshian; Panigrahi (2020)
Business models	Personalized service	Sorooshian; Panigrahi (2020)
	Corporate communication	Pereira; Romero (2017); Fatorachian;Kazemi (2018); Rao; Prasad (2018); Herceg *et al*. (2020)
	Operational performance	Felsberger *et al*. (2020)
	Information management	Corallo *et al*. (2020); Mahesh *et al*. (2020); Sorooshian; Panigrahi (2020)
	Trade relations	Nagy *et al*. (2018)
Social	Unemployment	Nafchi; Mohelská (2018); Jagannathan *et al*. (2019); Kumar *et al*. (2020); Raj *et al*. (2020)
	Reducing accidents at work	Sorooshian; Panigrahi (2020)
	Psychosocial risks	Ling *et al*. (2020); Mian *et al*. (2020)
	Society 5.0	Aquilani *et al*. (2020)

Given the impacts discussed, the changes in business models due to digital transformation are evident. Implementing Industry 4.0 in manufacturing affects corporate communication and adopting digitization and information management tools with real-time resources to add value by creating dialogues within the organizational structure, providing a unified communication platform (Rao and

Prasad, 2018). Technologies and process integration generate a flexible manufacturing environment by enabling customized ways of meeting demand (Sorooshian and Panigrahi, 2020), impacting product quality, costs, productivity, meeting customer expectations, and thus promoting significant operational performance (Felsberger *et al*., 2020).

The high degree of connectivity of industrial processes and the circulation of information in real-time reflects its impacts on managing privacy and data protection, impacting risk management, affecting workers, the quality of the final product, and process management (Sorooshian and Panigrahi, 2020). In contrast, information technology favors decision-making based on operational, economic, and market data and indicators (Corallo *et al*., 2020; Sorooshian and Panigrahi, 2020). Nagy *et al*. (2018) reported that the impacts of Industry 4.0 go beyond the company's internal business, extending to business relationships at the levels of the supply chain, suppliers, customers, and manufacturers. In this context, the trend of a digital ecosystem emerges where suppliers, manufacturers, and customers can share relevant information and data with the help of the internet.

As for the social impacts, the digital transformation promoted by Industry 4.0 generates a social environment of uncertainty, in which automation, digitalization, and disruptive technologies of the fourth industrial revolution should replace certain work functions previously performed by humans and thus promote unemployment (Nafchi and Mohelská, 2018; Raj *et al*., 2020). Although the benefits of adopting advanced technology resources in manufacturing processes impact the reduction of occupational accidents (Sorooshian and Panigrahi, 2020), for instance, this environment of uncertainty generates psychosocial risks, impacting the fields of health, safety, and occupational health (Ling *et al*., 2020; Mian *et al*., 2020).

The perspectives of advanced manufacturing solutions, spread by Industry 4.0, such as augmented reality, the internet of things, robotics, big data, and cyber-physical systems, may have aspects that are not considered positive in the labor market, environment, and business models. Nonetheless, digital transformation technologies can improve working conditions, create new sustainable business models, increase the operational and economic performance of companies, thereby guiding social welfare in a comprehensive way (Aquilani *et al*., 2020), and this positive perspective of the impacts of Industry 4.0 leads to the concept of Society 5.0.

The transition from the current industrial system to digital transformation, as well as the transition from today's society to one that absorbs the challenges and opportunities of Industry 4.0, have been the subject of study and speculation, bringing the need to understand both the extent of the impacts of the fourth industrial revolution on manufacturing and the challenges of this transition.

3.2 Industry 4.0 challenges for manufacturing

Industry 4.0 has been spreading worldwide as a new strategy for economic growth, innovation, global competitiveness; it has as pillars for the reinvention of the manufacturing industry the digitalization, intelligent manufacturing, and integration of processes and services. Despite the potential for manufacturing innovation, adopting concepts and resources disseminated by Industry 4.0 presents some challenges that reflect the aforementioned impacts.

Three latent challenges of the fourth industrial revolution are highlighted by Schwab and Davis (2018): (i) ensuring its benefits are distributed fairly without generating further social inequalities; (ii) managing potential externalities of digital transformation regarding risks and data; and (iii) ensuring the leadership of Industry 4.0 is human-to-human. Nagy *et al*. (2018) categorize Industry 4.0 challenges into technological, organizational, labor market, and market culture, while Horváth and Szabó (2019) divided the challenges into process integration technologies, organizational factors, management, financial resources, and human resources. The challenges identified in the studies were categorized as (i) management, (ii) governments, (iii) implementation, (iv) labor, (v) operation, and (vi) security (Table 3).

The integrated data management present in smart manufacturing processes leads to the need for business management to transform data into useful information and knowledge for decision making through big data analytics (Xu *et al*., 2018; 2019; Hughes *et al*., 2020). Management challenges still encompass the demand for managerial competence capable of promoting the transition from the current state of manufacturing to smart manufacturing processes (Nagy *et al*., 2018; Kipper *et al*., 2019; Contador *et al*., 2020).

Table 3 – Potential challenges of Industry 4.0 on manufacturing.

Challenges	Characteristics	Authors
Management	Big data analysis	Fatorachian;Kazemi (2018); Nagy *et al*. (2018); Xu *et al*. (2018); Hughes *et al*. (2020)
	Sustainable development - ONU	Hughes *et al*. (2020)
	Management skills	Nagy *et al*. (2018); Kipper *et al*. (2019); Contador *et al*. (2020); Herceg *et al*. (2020)
	Organizational culture	Kamblea *et al*. (2018); Nagy *et al*. (2018); Horváth; Szabó (2019); Herceg *et al*. (2020)
	Lack of knowledge	Mittal *et al*. (2018); Erro-Garcés (2019); Stentoft; Rajkumar (2019); Kumar *et al*. (2020); Ling *et al*. (2020); Stentoft *et al*. (2020)
	Investments in research and development	Ling *et al*. (2020)
	Relocation of human capital	Raj *et al*. (2020); Spöttl; Windelband (2020)
Government	Policies for the development of Industry 4.0	Raj *et al*. (2020); Rojko *et al*. (2020); Stentoft *et al*. (2020)
Implementation	Internet coverage/ connectivity	Kamblea *et al*. (2018); Xu *et al*. (2018); Ling *et al*. (2020)
	Technological infrastructure	Lee *et al*. (2017); Fatorachian;Kazemi (2018); Kamblea *et al*. (2018); Mittal *et al*. (2018);Moktadir *et al*. (2018); Nafchi; Mohelská (2018); Nagy *et al*. (2018);Saniuk; Saniuk (2018); Xu *et al*. (2018); Kipper *et al*. (2019); Panetto *et al*. (2019); Prause (2019); Kumar *et al*. (2020); Mahesh *et al*. (2020); Masooda; Sonntaga (2020); Mian *et al*. (2020); Pessôa; Becker (2020); Raj *et al*. (2020); Rauch; Vickery (2020); Shi *et al*. (2020)
	Standardization	Xu *et al*. (2018); Kumar *et al*. (2020); Raj *et al*. (2020); Stentoft *et al*. (2020); Stentoft; Rajkumar (2019)
	Financial resources	Hartmann; Hattingh (2018); Kamblea *et al*. (2018); Mittal *et al*. (2018); Nagy *et al*. (2018); Horváth; Szabó (2019); Contador *et al*. (2020); Herceg *et al*. (2020); Kumar *et al*. (2020); Ling *et al*. (2020); Mahesh *et al*. (2020); Masooda; Sonntaga (2020); Mian *et al*. (2020); Raj *et al*. (2020); Stentoft *et al*. (2020); Stentoft; Rajkumar (2019)
Workforce	Professional qualification	Hartmann; Hattingh (2018); Kamblea *et al*. (2018); Nagy *et al*. (2018); Erro-Garcés (2019); Horváth; Szabó (2019); Jagannathan *et al*. (2019); Contador *et al*. (2020); Herceg *et al*. (2020); Kumar *et al*. (2020); Ling *et al*. (2020); Mian *et al*. (2020); Raj *et al*. (2020); Stentoft *et al*. (2020); Stentoft; Rajkumar (2019)

	Employee resistance	Erro-Garcés (2019); Kipper *et al*. (2019); Stentoft; Rajkumar (2019); Contador *et al*. (2020); Ling *et al*. (2020); Stentoft *et al*. (2020)
	Technological support to the operator	Pereira; Romero (2017)
Operation	Scalability	Ling *et al*. (2020)
	Interoperability	Fatorachian;Kazemi (2018); Horváth; Szabó (2019); Zeid *et al*. (2019); Raj *et al*. (2020)
	Energy optimization	Humayun *et al*. (2020)
	Product customization	Marques *et al*. (2017)
Security	Management of information security	Ilvonen *et al*. (2018)
	Cybersecurity	Pereira *et al*. (2017); Fatorachian;Kazemi (2018); Kamblea *et al*. (2018); Moustafa *et al*. (2018); Nagy *et al*. (2018); Xu *et al*. (2018); Culot *et al*. (2019); Stentoft; Rajkumar (2019); Contador *et al*. (2020); Corallo *et al*. (2020); Humayun *et al*. (2020); Kumar *et al*. (2020); Ling *et al*. (2020); Mahesh *et al*. (2020); Mantravadi *et al*. (2020); Mian *et al*. (2020); Raj *et al*. (2020); Stentoft *et al*. (2020)

However, an organizational culture resistant to change coupled with a lack of knowledge about the opportunities, perspectives, and concepts of Industry 4.0 from managers and leaders results in a significant internal challenge to be overcome before adopting an innovation-oriented business model and smart manufacturing (Mittal *et al*., 2018; Erro-Garcés, 2019; Stentoft and Rajkumar, 2019). Consequently, a plastered industrial evolution state does not prioritize investments in research and development, a necessary action to minimize implementation uncertainties and assess effective investment opportunities (Ling *et al*., 2020).

In addition to the described challenges, corporate management still needs to manage human capital after adopting digital transformation, since automation and digitalization may eliminate positions, making it necessary to reassign employees and attract skilled labor to meet the new demands (Raj *et al*., 2020; Spöttl and Windelband, 2020). Moreover, in the managerial scope, balancing the complexities inherent to smart manufacturing with sustainability and environmental factors is essential, aligning industrial processes with the sustainable development goals recommended by the United Nations (Hughes *et al*., 2020).

At the governmental level, government readiness to promote industrial initiatives to adopt and implement smart manufacturing technologies is also a challenge for adopting digital transformation to establish priorities, standards, regulations, and national and international certifications (Raj *et al*., 2020; Rojko *et al*., 2020), especially to guide the implementation in small and medium-sized enterprises (Stentoft *et al*., 2020).

The main implementation challenges identified pertain to financial resources for Industry 4.0 adoption and technology infrastructure. Innovation-oriented technology resources and smart manufacturing require high investments, which can create barriers to adopting Industry 4.0 practices (Hartmann and Hattingh, 2018; Kumar *et al*., 2020; Mahesh *et al*., 2020; Masooda and Sonntaga, 2020; Stentoft and Rajkumar, 2019).

The lack of knowledge of the resources coming from digital transformation also generates fear of investing in technological resources that do not meet the needs of the processes, as well as adopting inappropriate practices, especially in small and medium-sized companies that have limited resources for investments (Horváth and Szabó, 2019; Mittal *et al*., 2018; Stentoft *et al*., 2020).

The enterprise technological infrastructure is also a challenge of implementing Industry 4.0 since, in large part, companies do not have resources with intelligent technology in their manufacturing processes. Thus, to join the digital transformation, it is pivotal to invest in sophisticated equipment (Xu *et al*., 2018; Kumar *et al*., 2020; Kipper *et al*., 2019; Pessôa and Becker, 2020). Another technology infrastructure problem is the supply of software and technology equipment for digital transformation adoption that do not yet serve all markets (Mittal *et al*., 2018; Masooda and Sonntaga, 2020; Prause, 2019).

The high connectivity between integrated manufacturing systems and the high flow of data coming from the processes demand internet coverage with adequate speed to supply the production flow (Kamblea *et al*., 2018; Xu *et al*., 2018; Ling *et al*., 2020), creating yet another challenge to implement smart processes.

Industrial standardization has also been identified as a potential challenge for implementing Industry 4.0 given the integration of complex technologies, thus requiring standardization at various levels of the production chain to ensure the successful implementation of digital capabilities (Xu *et al*., 2018; Kumar *et al*., 2020; Raj *et al*., 2020; Stentoft and Rajkumar, 2019).

What is more, workforce challenges include specialized professional qualifications to perform in a smart manufacturing context, employee resistance to joining the digital transformation, and adequate operator support regarding digital operation and interface (Erro-Garcés, 2019; Pereira and Romero, 2017; Stentoft and Rajkumar, 2019). Qualifying the workforce will be a challenge in order to make industrial advancement possible (Kumar *et al*., 2020); additionally, employee resistance may significantly hamper the introduction of disruptive technologies in manufacturing (Horváth and Szabó, 2019). Companies that adhere to digital transformation have as a challenge the digital support to employees exposed to different interactions with machinery, processes, and new tasks (Pereira and Romero, 2017).

The challenges of scalability, interoperability, energy optimization, and product customization characterize potential operational challenges for companies adopting smart manufacturing (Zeid *et al*., 2019). The scalability challenge arises as physical objects become connected to the manufacturing network due to the variety of possibilities present in the processes, referring to the system's ability to grow to meet demand without losing quality (Ling *et al*., 2020). The flexibility of the manufacturing network will be essential to meet customer demands for personalized service and products (Marques *et al*., 2017).

Interoperability represents a challenge of integrating systems and their ability to communicate, including service internet, human and organizational resources, as well as how the system manages data flow (Fatorachian and Kazemi, 2018; Zeid *et al*., 2019; Raj *et al*., 2020), energy optimization required due to high demand coming from process integration and the high flow of data circulating in real time (Humayun *et al*., 2020).

As the physical world connects with the virtual environment, security problems will become a serious challenge to be overcome by organizations. In the context of integrated and real-time connected systems, one of the most significant organizational concerns relates to data security and information privacy (Pereira *et al*., 2017; Moustafa *et al*., 2018; Xu *et al*., 2018; Culot *et al*., 2019; Mantravadi *et al*., 2020).

Cyber attacks can be motivated by state actors, criminal organizations, politicians, activists, and competitors with the goal of financial theft, piracy, sabotage, and counterfeiting (Mahesh *et al*., 2020). Lastly, security challenges include information security management related to knowledge protection, and in the face of knowledge sharing, it is paramount to define organizational boundaries to protect the domains of knowledge base, strategy, and business innovation (Ilvonen *et al*., 2018).

4. Conclusions

This paper proposed an analysis of the impacts and challenges of Industry 4.0 for manufacturing. To this end, a systematic literature review was conducted and based on studies published in journals until 2020, addressing the potential impacts and challenges of Industry 4.0 for manufacturing. The method used focused on three stages: planning, conducting, and reporting and dissemination. The third stage of the method presents, initially, a bibliometric analysis containing the temporal evolution report of the researched publications. Next, results and discussions about the potential impacts and challenges of Industry 4.0 in manufacturing identified in the selected studies were presented.

The systematic literature review made it possible to identify seven types of potential impacts of Industry 4.0 on manufacturing: environmental, competitiveness, economic, educational, labor market, business models, and social. We observed, through the publications, an emphasis on research on the environmental impact related to energy consumption arising from systems integration and connectivity. In the economic scope, the impact of increased productivity and revenue growth is in evidence in the publications due to the possibilities of Industry 4.0 technologies.

Technology will play a leading role in restoring economic, productive, and competitive growth. Nonetheless, there is a need to emphasize education guided by new social and market skills and competencies so that it is possible to intensify the application of technological innovations and generate positive impacts in all spheres of society, emphasizing the need to adapt the education structure. In addition to these impacts, changes in business models regarding corporate communication and social changes due to concerns about the potential increase of unemployment have been part of the impacts of Industry 4.0 in manufacturing.

The systematic review also allowed us to identify the potential challenges of digital transformation for manufacturing, which were divided into management, governance, implementation, workforce, operation, and security. These challenges were aligned with the identified impacts of Industry 4.0. The implementation challenge most discussed in the literature was technology infrastructure, illustrating the limited organizational resources available for smart manufacturing and the need for investing in sophisticated technologies. The skilled labor challenge reflected the impacts of Industry 4.0 on the labor market and education.

Little research has addressed the overall effects of Industry 4.0 on manufacturing. The explanations presented herein regarding the potential impacts and challenges of digital transformation in manufacturing aim to contribute and support academics and professionals who apply efforts in understanding the concepts and scope of the fourth industrial revolution.

The fourth industrial revolution is booming and, in addition to numerous opportunities, it also presents several impacts and challenges for manufacturing that are reflected in the sustainability of society as a whole. The effects and challenges discussed reflect the dynamic and fast-paced environment disseminated by the digital transformation. Therefore, collective actions of business leaders, governments, social organizations, academia, among others, to spread knowledge about the opportunities and potential results of Industry 4.0, as well as guidelines about its implementation in a sustainable way, in an ethical way, minimizing the uncertainties about its transition and potential challenges and impacts to society, are fundamental for the progress of this transformation. For future studies, we suggest developing scientific studies capable of guiding remedial solutions to circumvent the challenges and impacts of Industry 4.0 not only in manufacturing but in the academic and social environments and other limited sectors of consistent guidance on when it is necessary to start the transition to the transformation, how to proceed with this transition, and how to deal with its uncertainties.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

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