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Smart manufacturing implementation: identifying barriers and their related stakeholders and components of technology

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Abstract

Purpose – One of the achievements of the fourth industrial revolution is smart manufacturing, a manufacturing system based on Industry 4.0 technologies that will increase systems' reliability, efficiency and productivity. Despite the many benefits, some barriers obstruct the implementation of this manufacturing system. This study aims to analyze these barriers.

Design/methodology/approach – One of the measures that must be taken is to identify and try to remove these barriers, which involves identifying the stakeholders and components of technology associated with each barrier. As such, the primary purpose of this paper is to present a systematic literature review in the field of smart manufacturing with a focus on barriers to implementation related to the stakeholders and components of technology.

Findings – This research conducted a systematic literature review in Scopus and Web of Science databases and considered the studies published until 2021 were examined. The central question of this paper is answered based on this literature review, in which 133 related studies and 15 barriers were identified.

Practical implications – The significant gap observed in the literature review is that no research has been conducted to determine the stakeholders and components of technology related to the barriers, making it a potentially worthwhile subject for future research. In addition, the results of this study may help managers to implement smart manufacturing.

Originality/value – This study provides two main originalities. The former is helpful information for managers to make effective decisions when they face smart manufacturing barriers. The latter is related to identifying critical research gaps through systematic literature review.

Keywords Smart manufacturing, Barriers, Components of technology, Stakeholders

Paper type Research Paper

JEL classification – M11, M15, O25, O32, O33

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1. Introduction

Technological advancements and the process of digitization have garnered significant interest from both developed and developing nations (Ahmed, 2020; ALshubiri *et al.*, 2023). In recent years, manufacturing has seen a new revolution called Industry 4.0 (Pasi, 2023). Industry 4.0 refers to the fourth industrial revolution, which uses cyber-physical systems, the internet, futuristic technologies and smart systems to facilitate human–machine interaction (Rocha *et al.*, 2022). One of the industry 4.0 achievements is smart manufacturing, a value-creating process that includes everything from design to production, logistics and service. Smart manufacturing is a network-based and connected manufacturing system that obtains all information on all equipment in time via the internet. In this manufacturing system, manufacturing methods are changed by automation, and in general, a dynamic and optimal manufacturing system is implemented (Park, 2016). The smartness of manufacturing systems has created many changes in some aspects of their traditional pattern, such as workforce, equipment, processes and collaborations. Making these changes requires the preparation of elements like new technologies (Chauhan *et al.*, 2021), skilled labor (Al-Salman and Salih, 2019) and the appropriate culture (Aggarwal *et al.*, 2019). Therefore, developing a smart manufacturing system is difficult, and its implementation in other companies and countries will face additional barriers because adapting to Industry 4.0 is highly complex (Raj *et al.*, 2019). Therefore, it is necessary to identify the barriers to smart manufacturing implementation.

When the barriers have been identified, some actions must be taken to remove them. One of the influential factors in implementing these measures is understanding the importance of stakeholders on the part of managers. Managers must strive to develop strategies and plan actions that meet the expectations of their stakeholders (Taghian *et al.*, 2015). Another factor that can be effective in taking action to remove barriers is to identify the components of technology with which each barrier is associated. Barriers may be related to *technoware, infoware, humanware* and *orgaware* (Haines and Sharif, 2006), and this classification helps select the appropriate strategies for removing each barrier. Despite the significance of these two factors, they have not been addressed in the existing literature. Articles of systematic review in the field of smart manufacturing and Industry 4.0 include Cioffi *et al.* (2020), who conducted a systematic literature review (SLR) involving smart manufacturing technologies, Osterrieder *et al.* (2020), who investigated research advances in smart manufacturing, and Cui *et al.* (2020), who conducted a systematic review of Big Data requirements and components in manufacturing. Other review articles are also listed in the Appendix (Appendix Table A1). The identified gap in the literature is a lack of a comprehensive review focusing on the barriers to adopting smart manufacturing practices. A major factor hindering organizations from embracing smart manufacturing is the presence of barriers that impede successful implementation. It is crucial to pinpoint these barriers, but taking action to remove them is equally important. This involves identifying the specific technologies associated with each barrier and understanding who benefits from or is impacted by them.

By bridging this knowledge gap, decision-makers can be equipped with the necessary insights to navigate the complexities of smart manufacturing implementation and make informed choices about appropriate strategies and actions. Furthermore, this enhanced understanding can facilitate stakeholder collaboration, fostering a more conducive environment for adopting smart manufacturing practices and ultimately driving positive outcomes for organizations and industries.

Addressing barriers to smart manufacturing implementation requires a holistic approach that considers the interplay between components of technology, stakeholders and organizational dynamics. Organizations can effectively navigate barriers and drive successful smart manufacturing initiatives by understanding the specific challenges associated with each barrier and engaging relevant stakeholders in targeted strategies, reflecting this study's main contribution.

This study is organized as follows: in Section 2, smart manufacturing is described. In contrast, Section 3 contains a review of articles on the SLR related to this research. Section 4 discusses the research methodology, which includes research questions, search strategies and selected articles. Section 5 five contains the research findings, including descriptive statistics of selected articles and answers to questions. Section 6 includes the discussion and conclusion.

2. Smart manufacturing

With the development of the Internet infrastructure, the fourth industrial revolution started at the beginning of the 21st century. The conceptual heart of Industry 4.0 is smart manufacturing, and everything revolves around this core entity that shapes the business model. The goal of the development of smart manufacturing is to improve productivity, efficiency, reliability and the control of final products (Narwane *et al.*, 2022a). Smart manufacturing, by using new technologies, increases operational capacity, reduces costs and reduces downtime (Kumar Hajoary, 2023; Moghaddam *et al.*, 2018). According to the National Institute of Standards and Technology, smart manufacturing is a unified system that responds immediately to variable demands, supply chain, customer needs and any changes in the factory condition (Tay *et al.*, 2021). Smart manufacturing has three components: smart devices, smart humans and smart products (Benotsmane *et al.*, 2019), which are within the context of Industry 4.0 technologies. Figure 1 shows the components and technologies of smart manufacturing. The smart device is the first component of smart manufacturing. It includes multi-agent systems that can be created through the cooperation of smart industrial robots, sensors, controllers and computer numerical control, increasing flexibility and competitiveness. Humans are another part of smart manufacturing, including the two groups of laborers and customers. The workforce using Industry 4.0 tools requires IT, manufacturing and logistics knowledge, whereas customers are influential in designing and producing smart products. The third component of smart manufacturing is smart products, which include everything from parts to the final product. These components and smart products are connected to smart devices through embedded sensors and control in this way (Benotsmane *et al.*, 2019). These components are embedded in the environment, resulting in new technologies such as the Internet of Things, cloud computing and additive manufacturing. In addition, smart manufacturing requires Smart Products, Smart Logistics, Smart Applications and Data Analysis (Benotsmane *et al.*, 2019).

With the emergence of smart manufacturing, many developed countries are trying to use advanced technologies in their manufacturing plants and enjoy the benefits of smart manufacturing. Smart manufacturing can benefit customers and organizations (Khan and Turowski, 2016). Benotsmane *et al.* (2019) introduced the benefits of smart manufacturing in both social and economic categories. They mentioned that economic benefits include optimization through self-regulation, self-control and self-adaptation; increased utility and efficiency in using machines and human resources; production of durable and cost-effective products; and reduced operating costs through constant performance measurement and evaluation of production processes. Social benefits include increasing the specialized workforce, the freedom of trained staff to express ideas and solutions in various situations and increased employee satisfaction.

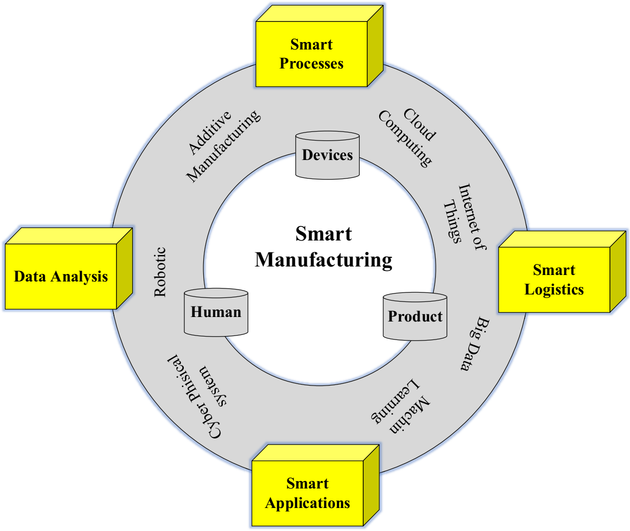


Figure 1. Components of smart manufacturing

Source: Benotsmane *et al*. (2019)

3. Main gaps of existing systematic literature review

A review of articles on the SLR involving Industry 4.0 and smart manufacturing shows the upward trend of systematic reviews in articles in these areas. These cases prove the importance of conducting a systematic review in the present study field. These articles can be placed in different categories, as shown in Figure 2.

Several studies in the systematic review are presented in Appendix (see Appendix Table A1) as examples. Some of these studies examined the extent of knowledge in the smart supply chain field and the smart supply chain field and supply chain dimensions that have been influenced by Industry 4.0 (Abdirad and Krishnan, 2020; Tiwari, 2021). Another group of studies looked at investigated the relationships between different manufacturing systems, such as LARG (Lean, Agile, Resilient and Green) (Amjad *et al.*, 2020), Sustainability (Birkel and Müller, 2021; Cioffi *et al.*, 2020; Kamble *et al.*, 2018a) and Agility (Mrugalska and Ahmed, 2021) and Industry 4.0. This research category also examined the barriers to the relationship between these manufacturing systems and Industry 4.0. Industry 4.0 technologies is another topic many scholars have systematically reviewed (Cui

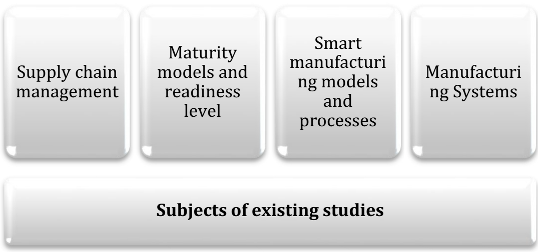


Figure 2. Classification of existing SLR

Source: Authors own work

et al., 2020; Szász *et al.*, 2020; Zheng *et al.*, 2021). The impact of technologies on the performance of manufacturing systems is the subject of some studies in this category, while others examine smart manufacturing models and how their processes work (Bueno *et al.*, 2020; Egger and Masood, 2019; Osterrieder *et al.*, 2020). The final category of studies examined the maturity models and the level of industry readiness to deploy Industry 4.0 (Mittal *et al.*, 2018; Sony and Naik, 2019), looking at the key elements of Industry 4.0 implementation and smart manufacturing and identifying readiness assessment methods.

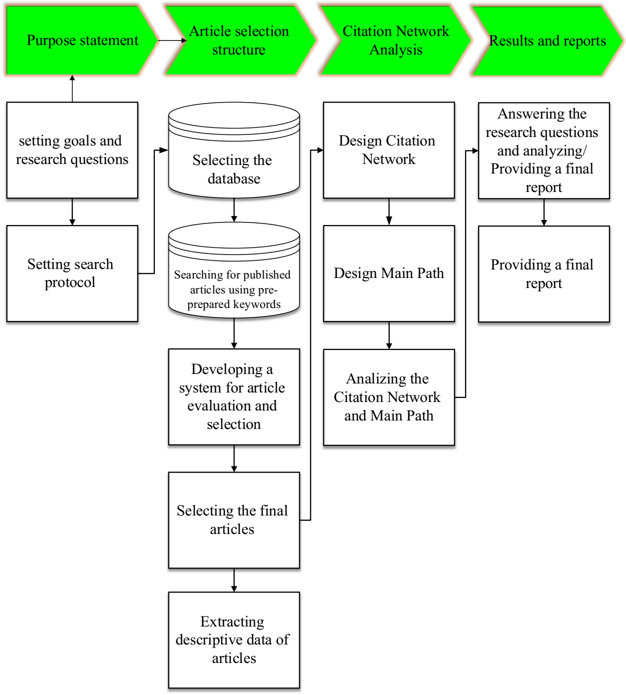
Apart from these studies, Narwane *et al.* (2022b) analyzed the challenges of implementing smart manufacturing. These researchers only focused on collecting the challenges and the cause-effect relationships between them. However, to effectively address and overcome the challenges and barriers inherent in implementing smart manufacturing, it becomes imperative to ascertain the stakeholders involved and the specific component of technology associated with each challenge or barrier. This knowledge can aid decision-makers in making informed choices regarding appropriate strategies and actions.

4. Methodology

In this study, we conducted an SLR involving barriers to implementing smart manufacturing. Reviewing the literature in traditional ways may not cover all the published research in the field and may mislead the authors in choosing ideas for future articles (Lee, 2023). An SLR is a tool designed to extract and summarize data in the initial research available in databases (Cioffi *et al.*, 2020; Pacheco *et al.*, 2018). Conducting a SLR helps identify and compile relevant information (Egger and Masood, 2019) and, in addition, introduces relevant ideas to the scientific community in the field (Cioffi *et al.*, 2020). SLR is a structured and repeatable scientific method that synthesizes and categorizes existing information using a precise and objective process (Núñez-Merino *et al.*, 2020).

In recent years, SLRs have attracted the attention of many scholars in various fields, such as medicine, computer science, engineering, business management and accounting and decision sciences. The method was first presented by Tranfield *et al.* (2003). The technique has also been developed in some studies (Mrugalska and Ahmed, 2021; Zonta *et al.*, 2020). In this study, the approach proposed by Tranfield *et al.* (2003) is combined with the citation network analysis (CAN) and the main path. First, the goal is set, and the research questions are identified. Then, a systematic search in the selected databases is conducted based on the terms and keywords that were collected based on the research questions. Afterward, selecting criteria in several stages will choose appropriate articles that can answer the questions. Finally, the findings of the selected papers are identified and analyzed. Among the final steps of SLR, two methods of CNA and main path analysis (MPA) can be used.

As mentioned, an SLR reveals major contributions and research gaps in a given area. At the same time, a method called Citation Network, which was developed by Garfield *et al.* in 1996, shows a structure of the devolvement of that area over time (Wilding *et al.*, 2012). CNA evaluates the interaction between research in a given field by examining references. The CNA identifies the known articles and theories that affect the field's development (Gustafsson *et al.*, 2014). The primary purpose is to identify and describe different patterns between different actors. These actors are different according to the type of research. In this study, the actors are articles involving barriers to implementing smart manufacturing. Figure 3 shows the research framework.



Source: Authors own work

Figure 3.
Research implementation process

After conducting a CNA, using MPA can be practical. The objective of the MPA is to spot the leading articles of each timespan, which points out the main direction of the studies. MPA helps with the dynamic assessment of the targeted papers (Wilding *et al.*, 2012). Hummon and Dereian (1989) introduced this method to specify the main path of a scientific field in the CNA (Hummon and Dereian, 1989). In this method, there is a weighted link between every node (research). MPA consists of three steps (Wilding *et al.*, 2012):

First, after forming a zero-one network of the nodes, the weight is formulated by using $Weight_{ij} = \frac{TP_{ij}}{TSS_j}$ equation. In this equation, TP_{ij} is the total number of paths in the network j, consisting of all the citations, and TSS_j is all the paths between principles and purposes in network j; this method is called search path count (SPC) (Batagelj, 1989). In the SPC method, all the paths between the principle and the purpose are considered, and the weight is calculated by counting all the paths from the principle to the purpose. In the second step, the main paths of the links between the researches are recognized using traversal weights. These paths are considered to be the mainstream of the literature. Finally, the main elements or main nodes of the mainstream are selected. Values between zero and one are taken as the threshold for this purpose to eliminate the extraneous elements of the research; the number is assumed to be 0.5 here. The study uses Pajek software to determine its critical path (see (Statsenko *et al.*, 2022)).

4.1 Research questions

Existing literature lacks a comprehensive review focusing on the barriers hindering the adoption of smart manufacturing practices within the context of Industry 4.0 technologies.

The presence of barriers presents a significant challenge for organizations seeking to embrace smart manufacturing, impeding successful implementation efforts. Pinpointing these barriers is crucial, but the action taken to mitigate them is equally essential. This necessitates identifying specific technologies associated with each barrier and comprehensively understanding the stakeholders impacted by or influencing these barriers.

Now, the main research questions (RQ) can be directly derived from this research gap:

RQ1. What barriers make Industry 4.0 technologies incompatible in manufacturing and smartification?

Despite the benefits that compliance with Industry 4.0 may bring, there is a long way, with numerous barriers, for organizations to overcome these barriers and realize the potential benefits (Frank *et al.*, 2019). Many organizations worldwide either do not have a plan to implement Industry 4.0 or have a plan they do not implement because of the barriers they encounter (Raj *et al.*, 2019). Therefore, identifying and finding ways to address these barriers seems critical in motivating organizations worldwide:

RQ2. What is the appropriate classification of the barriers to implementing smart manufacturing? How will these factors fall into the identified categories?

Implementing smart manufacturing, in addition to changes in technological infrastructure, brings about other changes in organizations. Changes in market boundaries and organizational strategies are examples that require new business models. Furthermore, organizations need to develop capabilities and a smart workforce and create a conducive environment for innovation to become smart (Shamim *et al.*, 2016). All these developments generate barriers that can only be removed with managerial measures because having a rational and scientific management approach in an organization leads to efficient planning, organization and control of tasks (Maskuriy *et al.*, 2019). Reviewing the literature regarding barriers makes the lack of managerial perspective clear. At the same time, the technological approach has received much more attention (Schneider, 2018). To close that gap, all the barriers identified in this SLR have been categorized so that the management approach and the executive and technological infrastructure are included. To consider the managerial approach, the classification introduced by Schneider (2018) (see Table 1) is used, and to classify with the executive infrastructure approach, the classification presented by Alaa *et al.* (2017) is followed (see Figure 4):

RQ3. To which category of technology components does each identified barriers belong?

According to the definition presented by the United Nations Industrial Development Organization, technology consists of the knowledge and skills necessary to produce goods and services that result from the power of human thinking and cognition and the combination of laws in nature. In other words, it includes the application of science in industries using procedures and directional studies. There are various categories of technology components in the existing literature on technology. (Haines and Sharif, 2006) introduced technology with physical, human, knowledge and social components, called *technoware*, *humanware*, *infoware* and *orgaware* (Marlyana *et al.*, 2018).

The technology embodied in the various tools and machines used to produce goods and services is called *technoware*, including tools, equipment and machinery. *Humanware* is a technology embodied in people (e.g. workers, technicians, engineers and managers), like experiences, skills, knowledge, creativity and mental manifestations. *Infoware* is the

Table 1.
Managerial industry 4.0 challenges: managerial approach

Managerial challenges	Description
Analysis and strategy	This category includes issues that companies need to discuss to decide how to implement Industry 4.0. Investigating the stimuli that will cause change falls into this category
Planning and cooperation and networks	Planning issues for running Industry 4.0 fall into this category. Extensive communication cannot be easily established and brings problems and challenges. These risks fall into the category of cooperation and networks.
Business models	With the emergence of Industry 4.0 technologies, older business models will no longer fit. Therefore, a new business model must be developed. There will also be drivers and issues in changing the business model that can be placed in this category
Human resources	Based on smart manufacturing implementation, the role of the workforce has changed, and thus the required expertise and skills have also changed. These changes and developments will also lead to many issues in this category
Change and leadership	Because of the changes resulting from the implementation of Industry 4.0, governance, control and coordination of organizational and cultural developments are among the issues facing organizations with Industry 4.0 will face. These issues and challenges fall into the category of change and leadership

Source: Schneider (2018)

technology embodied in the various information and documents required to produce goods and services, including procedures, theories, descriptions of processes, observations, instructions and a set of software. *Orgaware*, technology embodied in institutions (e.g. workshops, factories and laboratories) is used in creating, completing, applying and development of technology. All organizing and managing operations to manage the institutions involved in technological activities can be located in this area (Sulistiyowati and Jakaria, 2018):

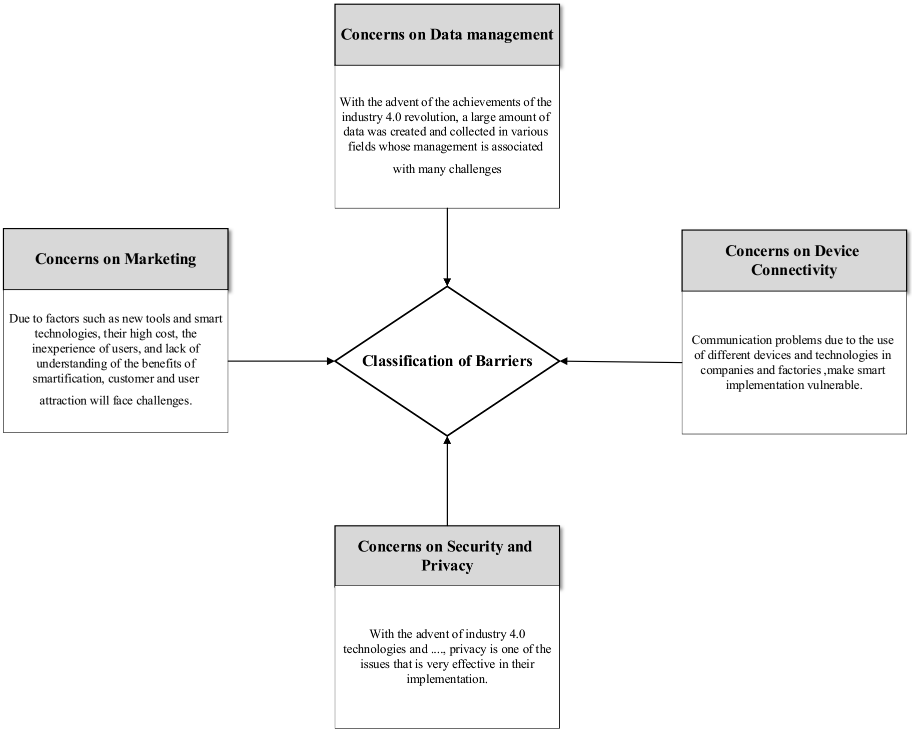
RQ4. Which stakeholders does each barrier affect or is affected by?

Freeman (1984) defined stakeholders as a group or individuals who can affect or be influenced by the achievement of an organization's goals (Gamble *et al.*, 2021). According to the definition provided, stakeholders play a vital role in advancing the organization's goals. Therefore, their management can affect the success of an organization. The power of stakeholders and their relationship to the issues facing the organization increases their importance to the survival of the organization (Savage *et al.*, 1991). Accordingly, it can be concluded that identifying the Stakeholders associated with each barrier in the implementation of smart manufacturing can be very helpful in managing those barriers. Thus, by identifying the factor influencing or being influenced by each barrier, we can identify the necessary measures and plan for their implementation. Figure 5 contains the possible stakeholders associated with the barriers.

These refined research questions directly address the core aspects of the research gap, facilitating a focused investigation into the barriers and challenges surrounding the adoption of smart manufacturing practices.

4.2 Search strategies

The next step is to determine the key terms related to the topic and the selection of databases. Based on the studies conducted in smart manufacturing and production during



Source: Alaa *et al*. (2017)

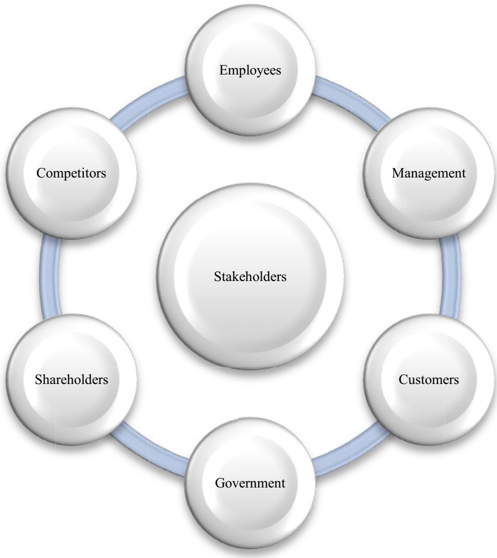
Figure 4. Classification of challenges: executive infrastructure approach

the fourth industrial revolution and considering the goals and questions of the research, the words and phrases included in Figure 6 are collected.

Using more than one digital library (DL) prevents certain studies from being overlooked and biased in reviewing published studies (Núñez-Merino *et al.*, 2020). Therefore, the Scopus and Web of Science (WoS) DLs were selected for this research, providing a complete set of published research. The Scopus and WoS academic databases include research in various areas, such as social sciences, life sciences, health sciences and physical sciences, and therefore be very useful for interdisciplinary research. Both selected databases support the Boolean search system [1]. Thus, while searching, it is possible to use operators like NOT, OR and AND to identify the most relevant studies (Bag *et al.*, 2018). In addition, with Scopus and Web of Science, the results can be easily organized, and output can be obtained through software like Publish and Prish and analyzed through VOSviewer (Wilding *et al.*, 2012).

4.3 Article selection

Related articles are extracted by searching for keywords in Scopus and WoS databases. Then, based on the relationship between the research, the questions and the criteria determined in Table 2, relevant research studies are selected step by step. Figure 7 shows the search and selection process.



Sources: Carlucci et al. (2018); Gurzawska, Mäkinen, and Brey (2017); Schantz and Von (2007); Sirgy (2002)

Figure 5.
Key Stakeholders

"Fourth industrial revolution" OR "Fourth revolution" OR "I 4.0" OR "Industrial revolution 4.0" OR "Industr* 4.0" OR "Smart factory" OR "Smart supply chain" OR "Intelligent factory" OR "smart service" OR "Smart manufactur*"

AND

"Impact" OR "Adoption" OR "Opportunity" OR "Practice" OR "Solution" OR "Implement*" OR "Applicat*" OR "Readiness assessment" OR "Readiness" OR "Maturity model" OR " readiness model"

AND

"Challenge" OR "Barrier" OR "Obstacle" OR "Failure factor"

Source: Authors own work

Figure 6.
Searched keywords

Moher *et al.* (2009) proposed a flowchart for reporting a SLR, which is called "Preferred Reporting Items for Systematic Review and Meta-Analysis" (PRISMA). As can be seen in Figure 7, the PRISMA flowchart of the current research is given. According to this report, in the initial search, 7,876 articles were collected from two databases, 1,175 of which occurred in both databases and this number was removed from WoS; leaving 6,703 studies. After reviewing the titles of these research, 1,743 studies made it to the next step (reviewing their abstracts). A review of the abstracts showed that only 507 studies appear relevant. Finally, by examining the contents of the remaining 487 studies from the previous step, 133 studies are identified to answer the questions and realize the appropriate goals.

5. Results

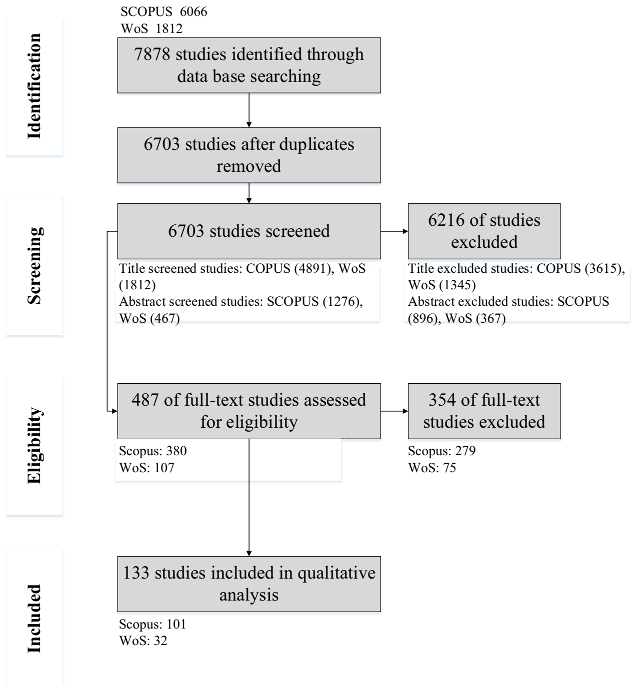
5.1 Citation network analysis

In this research stage, CNA of the articles is performed, using VOS viewer software. Figure 8 shows the citation analysis of the selected studies' keywords and terms that occurred more than three times. The results of keyword analysis show that the words "Industry 4.0," "Internet of Things," "Challenges" and "Barriers" have the most frequencies in selected articles, and this result indicates the proper search and selection of articles.

Criteria	Description
Criterion 1	Delete technical reports
Criterion 2	Eliminate research with less than four pages
Criterion 3	Eliminate research without the terms Industry 4.0, smart manufacturing and smart factory based on titles, abstracts and keywords
Criterion 4	Eliminate barrier-free research and key success factors in Industry 4.0 and smart manufacturing

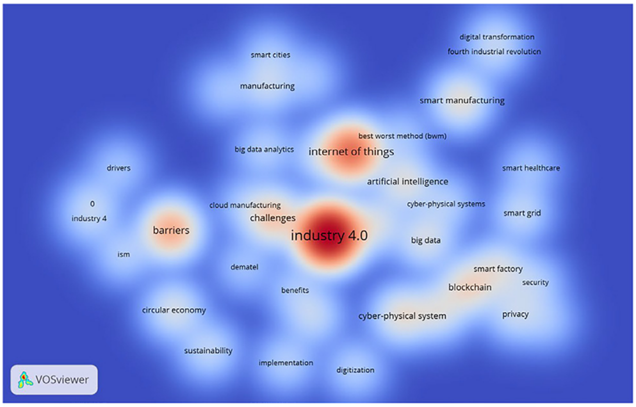
Source: Authors' own work

Table 2. Selection criteria



Source: Moher *et al.* (2009)

Figure 7. PRISMA flowchart of the systematic literature review



Source: Authors own work

Figure 8. Citation analysis of keywords

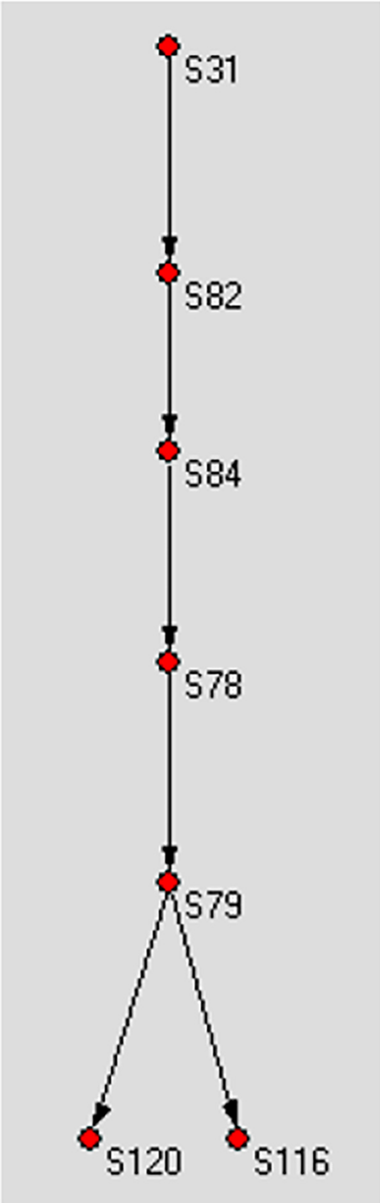
5.2 Main path

As mentioned earlier, to identify the leading articles in each period, MPA is used to determine the main path of the articles. In the graph resulting from this analysis, which is the skeleton of the research process governing the barriers to implementing smart manufacturing, the key research in each period is shown. The selection of these studies is not based on the number of citations but on the maximum number of citations between all paths over time. In Figure 9, seven studies from 1993 to 2021 have been selected and arranged according to the formula $Weight_{ij}$ (see Section 4).

Müller *et al.* (2018) work is at the top of the chart, investigating the challenges and opportunities as drivers of sustainability in Industry 4.0. This survey studies 746 manufacturing companies in Germany and shows the positive effects of Industry 4.0 in environmental, social and economic dimensions (Müller *et al.*, 2018). Sony and Naik (2020) performed an SLR on the key enablers of the Fourth Industrial Revolution. Their survey identifies ten critical elements of success, and each introduced as a solution for I4 challenges. In 2020, the study by Stentoft, Adsbøll Wickstrøm, *et al.* became popular. Drivers and barriers to implementing Industry 4.0 in small and medium-sized manufacturing companies are the topics of this study, and it investigates the readiness to adopt I4 technologies of four SMEs in Denmark. Raj *et al.* (2020) is another vital research of the area. This research identifies the barriers to adopting I4 technologies in the manufacturing sector and measures the relations between them using a Grey DEMATEL. Like Raj *et al.* (2020), Kumar *et al.* (2020a) also investigate the connections between I4 technologies' adaptation. Among the surveys 2021, Cugno *et al.* (2021) and Wankhede and Vinodh (2021a) are highly important. Cugno *et al.* (2021) assessed the barriers to implementing I4 technologies in Italy, whereas Wankhede and Vinodh (2021a) investigated the barriers to adopting cyber-physical systems in India. Likely, future studies will specifically address the barriers to I4 technology adaptation in different countries and industries.

5.3 Answers to research questions

RQ1. Barriers to the implementation of smart manufacturing.



Source: Authors own work

Figure 9.
Main path of studies

One of the most critical steps in implementing a new manufacturing system is identifying potential factors that can obstruct it. Reviewing the selected articles, all the barriers mentioned in the research conducted until 2021 were extracted. Studies show that these barriers can be seen in various manufacturing system components, such as customers, production technologies, information systems, human resources and government. Table 3 shows the barriers to smart manufacturing.

Big data issues: Big data consists of a set of data with a large volume that is processed at high speed. The use of Big data in smart manufacturing can be accompanied by barriers such as their complex management (Yu *et al.*, 2020b), access to Big data tools (Nasrollahi and Ramezani, 2020) and analysis and storage (Ahmed *et al.*, 2019). Big data issues were observed in the steel-making industry (Brichni and Guedria, 2018) and the construction industry (Alaloul *et al.*, 2020). There is also data in organizations without Big data features, and this category of data also faces issues that can get in the way of implementing smart manufacturing. Issues such as data access (Micheler *et al.*, 2019; Sharma and Sehrawat, 2020), data analysis (Fuller *et al.*, 2020; Khan *et al.*, 2020a, 2020b; Kumar *et al.*, 2020b; Nasrollahi and Ramezani, 2020; Rajput and Singh, 2019; Yu *et al.*, 2020b), a combination of diverse data and the difficulty of data collection (Bécue *et al.*, 2021; Dai *et al.*, 2020; Fernandez-Carames and Fraga-Lamas, 2019; Goh *et al.*, 2020; Luthra and Mangla, 2018; Masood and Sonntag, 2020; Mian *et al.*, 2020), lack of high-quality data (Masood and Sonntag, 2020; Nasrollahi and Ramezani, 2020; Raj *et al.*, 2019), data storage (Ghahramani *et al.*, 2020; Matt *et al.*, 2020; Micheler *et al.*, 2019) and data complexity (Li *et al.*, 2019) are barriers that fall into this category.

High costs: The implementation of a manufacturing system requires updating existing conditions to fit the new manufacturing system, and these changes require high investment costs (Aggarwal *et al.*, 2019; Choudhary *et al.*, 2020; Contador *et al.*, 2020; Alshubiri, 2022; Alraja *et al.*, 2023) which can be regarded as a significant barrier in the implementation of smart manufacturing due to the resistance of managers and investors when it comes to spending the money cost or a lack of financial resources.

Lack of adoptability: Fear of failure is a factor that may prevent organizations from adapting to the achievements of Industry 4.0. For fundamental organizational changes to occur, the willingness of managers to implement Industry 4.0 is essential. Thus, the lack of management support (Aggarwal *et al.*, 2019; Matt *et al.*, 2020; Nasrollahi and Ramezani, 2020; Raj *et al.*, 2020) is a barrier that will make the implementation of smart manufacturing difficult. Lack of government support (Falco and Kleinhans, 2018; Abbasi and Kamal, 2020; Aggarwal *et al.*, 2019; Machado *et al.*, 2019), lack of effective change management (Contador *et al.*, 2020; Ghadge *et al.*, 2020; Teck *et al.*, 2019) and poor research and development (Kumar *et al.*, 2021b, 2021c) can affect the adoptability of manufacturing systems.

Lack of new business models: A business model is a conceptual tool that includes a set of elements and their relationships and shows the company's logic for earning money. In other words, a business model specifies what and how it is to be provided by the organization. Therefore, when changing the organization's goals and processes during smartification, a new business model must be created (Chauhan *et al.*, 2021; Contador *et al.*, 2020; Nasrollahi and Ramezani, 2020). As a subset of barriers related to the business model, a lack of a systematic approach to implementation (Kumar *et al.*, 2020a), a lack of a roadmap and intangible strategy (Mian *et al.*, 2020) for implementation of smart manufacturing will also be considered as barriers.

Lack of skilled and trained workforce for I4.0: Making sure to align human values and skills with the goals of the organization is critical. The emergence of smart manufacturing makes it unavailable to experienced experts in this field (Brichni and Guedria, 2018;

	Barriers	References
B_1	Big data issues	Alaloul *et al.* (2020), Brichni and Guedria (2018), Dalzochio *et al.* (2020), Etemadi *et al.* (2021), Kumar *et al.* (2021b), Nasrollahi and Ramezani (2020), Singh *et al.* (2018), Wankhede and Vinodh (2021a), Yu *et al.* (2020b)
B_2	High costs	Abdul-Hamid *et al.* (2020), Ada *et al.* (2021), Aggarwal *et al.* (2019), Alaloul *et al.* (2020), Bag *et al.* (2021), Balas *et al.* (2022), Chong *et al.* (2002), Contador *et al.* (2020), Demirkesen and Tezel (2021), Faheem *et al.* (2018), Foukalas *et al.* (2019), Gallab *et al.* (2021), Gamil *et al.* (2020), Ghadge *et al.* (2020), Goh *et al.* (2020), Goswami and Daultani (2021), Kamble *et al.* (2018b), Karadayi-Usta (2020), Khan *et al.* (2020b), Luthra *et al.* (2018), Majumdar *et al.* (2021), Masood and Sonntag (2020), Matt *et al.* (2020), Moktadir *et al.* (2018), Motta *et al.* (2018), Müller (2019), Nasrollahi and Ramezani (2020), Obiso *et al.* (2019), Orzes *et al.* (2018), Postranecky and Svitek (2017), Rajput and Singh (2019), Rauch *et al.* (2019), Saleem *et al.* (2018), Singh *et al.* (2018), Wankhede and Vinodh (2021b), Wolf *et al.* (2018), Zhao *et al.* (2019)
B_3	Lack of adoptability	Abbasi and Kamal (2020), Abdul-Hamid *et al.* (2020), Ada *et al.* (2021), Aggarwal *et al.* (2019), Alaloul *et al.* (2020), Bajic *et al.* (2021), Bakhtari *et al.* (2020, 2021), Brichni and Guedria (2018), Chauhan *et al.* (2021), Chong *et al.* (2002), Choudhary *et al.* (2020), Contador *et al.* (2020), Cugno *et al.* (2021), Cui *et al.* (2021), Demirkesen and Tezel (2021), Gallab *et al.* (2021), Gamil *et al.* (2020), Ghadge *et al.* (2020), Goswami and Daultani (2021), Karadayi-Usta (2020), Klein *et al.* (2018), Kumar *et al.* (2021b, 2021c, 2020a, 2020b, 2021d), Lu and Xu (2019), Luthra and Mangla (2018), Machado *et al.* (2019), Majumdar *et al.* (2021), Mao *et al.* (2019), Matt *et al.* (2020), Mian *et al.* (2020), Mihovska *et al.* (2015), Müller (2019), Müller *et al.* (2018), Nasrollahi and Ramezani (2020), Obiso *et al.* (2019), Orzes *et al.* (2018), Ozkan-Ozen *et al.* (2020), Raj *et al.* (2019), Rajput and Singh (2019), Rauch *et al.* (2019), Rymarczyk (2020), Sharma and Sehrawat (2020), Shayganmehr *et al.* (2021), Singh and Misra (2021), Stentoft *et al.* (2020), Sulistiyowati and Jakaria (2018), Surati *et al.* (2021), Teck *et al.* (2019), de Vass *et al.* (2021), Verma *et al.* (2019), Wankhede and Vinodh (2021b), Zhao *et al.* (2019)
B_4	Lack of new business models	Contador *et al.* (2020), Kumar *et al.* (2021a, 2020a), Matt *et al.* (2020), Mian *et al.* (2020), Ozkan-Ozen *et al.* (2020), Pirvu and Zamfirescu (2017), Rauch *et al.* (2019), Teng *et al.* (2021)
B_5	Lack of skilled and trained workforce for I4.0	Aggarwal *et al.* (2019), Al-Salman and Salih (2019), Bag *et al.* (2021), Bajic *et al.* (2021), Brichni and Guedria (2018), Contador *et al.* (2020), Cugno *et al.* (2021), Demirkesen and Tezel (2021), Dikhanbayeva *et al.* (2021), Gallab *et al.* (2021), Kamble *et al.* (2018b), Khan *et al.* (2020b), Kumar *et al.* (2021b), Luthra *et al.* (2018), Mao *et al.* (2019), Motta *et al.* (2018), Murmura and Bravi (2018), Nasrollahi and Ramezani (2020), Raza *et al.* (2019), Sharma *et al.* (2021), Sharma and Sehrawat (2020), Shi *et al.* (2020), Singh *et al.* (2018), Sufian *et al.* (2019), Teng *et al.* (2021), Wankhede and Vinodh (2021b)
B_6	Lack of standardization	Ada *et al.* (2021), Bag *et al.* (2021), Brichni and Guedria (2018), Demirkesen and Tezel (2021), Halse and Jæge (2019), Kamble *et al.* (2018b), Luthra et al (2018), Matt *et al.* (2020), Wankhede and Vinodh (2021b)
B_7	Lack of technology integration	Abbasi and Kamal (2020), Ada *et al.* (2021), Ajmera and Jain (2019), Alaloul *et al.* (2020), Alromaihi *et al.* (2018), Bajic *et al.* (2021), Bakhtari *et al.* (2021), Bécue *et al.* (2021), Chauhan *et al.* (2021), Choudhary *et al.*

(*continued*)

Table 3.
Barriers to smart manufacturing

	Barriers	References
		(2020), Dai *et al.* (2020), Faheem *et al.* (2018), Fuller *et al.* (2020), Gamil *et al.* (2020), Goswami and Daultani (2021), Jamai *et al.* (2020), Kamble *et al.* (2018b), Klein *et al.* (2018), Kumar *et al.* (2021b, 2021c, 2020b, 2021d), Laeeq and Shamsi (2015), Lu and Xu (2019), Luthra and Mangla (2018), Machado *et al.* (2019), Majumdar *et al.* (2021), Mian *et al.* (2020), Motta *et al.* (2018), Obiso *et al.* (2019), Orzes *et al.* (2018), Ozkan-Ozen *et al.* (2020), Papakostas *et al.* (2017), Pirvu and Zamfirescu (2017), Pradhan and Agwa-Ejon (2018), Rajput and Singh (2019), Rauch *et al.* (2019), Rymarczyk (2020), Sadeghi *et al.* (2015), Saleem *et al.* (2018), Shi *et al.* (2020), Singh *et al.* (2018), Sony and Naik (2020), Stentoft *et al.* (2020), Teck *et al.* (2019), Verma *et al.*, 2019), Vimal Jerald *et al.*, 2017), Yang *et al.*, 2018), Yue *et al.*, 2015)
B_8	Legal issue	Juet (2014), Ada *et al.* (2021), Aggarwal *et al.* (2019), Dalzochio *et al.* (2020), Goswami and Daultani (2021), Juet (2014), Kamble *et al.* (2018b), Khan *et al.* (2020b), Matt *et al.* (2020), Qarabsh *et al.* (2020), Raza *et al.* (2019), Sharma *et al.* (2021)
B_9	Market issues	Ada *et al.* (2021), Ajmera and Jain (2019), Al-Salman and Salih (2019), Alromaihi *et al.* (2018), Chauhan *et al.* (2021), Contador *et al.* (2020), Cui *et al.* (2021), Dai *et al.* (2020), Faheem *et al.* (2018), Fuller *et al.* (2020), Gamil *et al.* (2020), Ghadge *et al.* (2020), Kumar *et al.* (2020b, 2021d), Lu and Xu (2019), Mian *et al.* (2020), Moktadir *et al.* (2018), Motta *et al.* (2018), Orzes *et al.* (2018), Raza *et al.* (2019), Rymarczyk (2020), Sadeghi *et al.* (2015), Singh and Misra (2021), Suciu and Hussain (2019), Verma *et al.* (2019), Yue *et al.* (2015), Zhao *et al.* (2019)
B_{10}	Scalability issue	Abdul-Hamid *et al.* (2020), Brichni and Guedria (2018), Ghadge *et al.* (2020), Li *et al.* (2019), Luthra and Mangla (2018), Masood and Sonntag (2020), Mazzei *et al.* (2020), Shi *et al.* (2020), Yadav *et al.* (2020), Yu *et al.* (2020b)
B_{11}	Security and privacy issues	Abdul-Hamid *et al.* (2020), Aggarwal *et al.* (2019), Bag *et al.* (2021), Bakhtari *et al.* (2020, 2021), Balas *et al.* (2022), Barik *et al.* (2017), Bogle (2017), Chauhan *et al.* (2021), Contador *et al.* (2020), Cui *et al.* (2021), Dai *et al.* (2020), Etemadi *et al.* (2021), Fernandez-Carames and Fraga-Lamas (2019), Fraga-Lamas and Fernández-Caramés (2019), Gallab *et al.* (2021), Goswami and Daultani (2021), Gupta *et al.* (2020), Kamble *et al.* (2020, 2018b), Khan and Turowski (2016), Khan *et al.* (2020a), Kumar *et al.* (2021b, 2021c, 2021d), Laeeq and Shamsi (2015), Li *et al.* (2019), Luthra *et al.* (2018), Luthra and Mangla (2018), Majumdar *et al.* (2021), Matt *et al.* (2020), Mazzei *et al.* (2020), Mian *et al.* (2020), Moktadir *et al.* (2018), Müller (2019), Nasrollahi and Ramezani (2020), Raj *et al.* (2020), Raza *et al.* (2019), Satyro *et al.* (2019), Sengupta *et al.* (2020), Singh and Misra (2021), Teck *et al.* (2019), Varga *et al.* (2020), Vimal Jerald *et al.* (2017), Yadav *et al.* (2020)
B_{12}	Structural issue	Ajmera and Jain (2019), Brichni and Guedria (2018), Chong *et al.* (2002), Kumar *et al.* (2021c, 2020a, 2021d), Laeeq and Shamsi (2015), Lepekhin *et al.* (2019), Lu and Xu (2019), Matt *et al.* (2020), Orzes *et al.* (2018), Sharma *et al.* (2021), Yang *et al.* (2018)
B_{13}	Unclear I 4.0 contributions and benefits	Bag *et al.* (2021), Cui *et al.* (2021), Demirkesen and Tezel (2021), Dikhanbayeva *et al.* (2021), Matt *et al.* (2020), Orzes *et al.* (2018), Raj *et al.* (2020), Satyro *et al.* (2019), Wolf *et al.* (2018)

(*continued*)

Table 3.

	Barriers	References
B_{14}	Weak interoperability	Abdul-Hamid *et al.* (2020), Ada *et al.* (2021), Balas *et al.* (2022), Brichni and Guedria (2018), Fraga-Lamas and Fernández-Caramés (2019), Klein *et al.* (2018), Kumar *et al.* (2021d), Matt *et al.* (2020), Mazzei *et al.* (2020), Müller (2019), Sufian *et al.* (2019), de Vass *et al.* (2021)
B_{15}	Weak IT infrastructure and smart facilities	Bag *et al.* (2021), Bakhtari *et al.* (2020), Bécue *et al.* (2021), Chauhan *et al.* (2021), Contador *et al.* (2020), Cui *et al.* (2021), Fernandez-Carames and Fraga-Lamas (2019), Fuller *et al.* (2020), Halse and Jæge (2019), Kamble *et al.* (2018b), Khan *et al.* (2020b), Kumar *et al.* (2021b, 2021c, 2020b), Li *et al.* (2019), Luthra *et al.* (2018), Luthra and Mangla (2018), Matt *et al.* (2020), Mian *et al.* (2020), Müller (2019), Orzes *et al.* (2018), Ozkan-Ozen *et al.* (2020), Qarabsh *et al.* (2020), Raj *et al.* (2020), Rajput and Singh (2019), Raza *et al.* (2019), Shi *et al.* (2020), Sjödin *et al.* (2018), Sony and Naik (2020), Stentoft *et al.* (2020), Teck *et al.* (2019), Wankhede and Vinodh (2021b), Yadav *et al.* (2020), Zhao *et al.* (2019)

Source: Authors' own work

Table 3.

Singh *et al.*, 2018). In addition, there is no skilled workforce to work in a smart factory with smart machinery (Al-Salman and Salih, 2019; Kamble *et al.*, 2018a). Therefore, continuous training of employees is required to teach people to work under new conditions (Parente *et al.*, 2020). Training staff to acquire new skills can be difficult and costly (Contador *et al.*, 2020; Micheler *et al.*, 2019; Sharma and Sehrawat, 2020; Teng *et al.*, 2021). Analyzing the steel-making industry (Brichni and Guedria, 2018), wood-furniture industry (Murmura and Bravi, 2018) and automotive industry (Wankhede and Vinodh, 2021b) shows that the lack of skilled and trained workforce for I4.0 is a vital barrier to the implementation of smart manufacturing.

Lack of standardization: There are various heterogeneous devices within the smart manufacturing system that adhere to different standards, making it very difficult to build connections between them (Brichni and Guedria, 2018; Faheem *et al.*, 2018; Goh *et al.*, 2020; Kamble *et al.*, 2018b; Luthra *et al.*, 2018; Matt *et al.*, 2020; Satyro *et al.*, 2019).

Lack of technology integration: The integration of technologies can affect communication between devices, units and companies, creating problems. Lack of standardization will lead to the use of heterogeneous machines and diversity of platforms (Sjödin *et al.*, 2018), issues such as unstable inter-firm connectivity (Gamil *et al.*, 2020; Guelzim *et al.*, 2016; Klein *et al.*, 2018; Mohamed *et al.*, 2020; Singh *et al.*, 2018), improper communication between devices and device inconsistencies (Fuller *et al.*, 2020; Gamil *et al.*, 2020; Moktadir *et al.*, 2018; Papakostas *et al.*, 2017; Yang *et al.*, 2018; Yu *et al.*, 2020a, 2020b).

Legal issues: Implementing smart manufacturing requires changes in rules and regulations to ensure proper security management. In implementing smart manufacturing, access to data and relations between employees and units undergo many changes. Therefore, new crimes can happen. Because existing laws cannot deal with them, new and appropriate regulations are needed (Aggarwal *et al.*, 2019; Dalzochio *et al.*, 2020; Juet, 2014; Kamble *et al.*, 2018b; Khan *et al.*, 2020b; Micheler *et al.*, 2019; Qarabsh *et al.*, 2020).

Market issues: There are also market-related barriers to implementing smart manufacturing. As competitors move towards smartification, competitive pressure on the organization to make the change (Orzes *et al.*, 2018) will increase because new and smart competitors will dominate the market, posing a threat to the organization (Bajic *et al.*, 2021;

Contador *et al.*, 2020; Moktadir *et al.*, 2018). However, fears of uncertain demand due to market disruption (Kumar *et al.*, 2020b) will cause the organization to resist implementing Industry 4.0 (Chauhan *et al.*, 2021; Gamil *et al.*, 2020; Singh and Misra, 2021). Demand forecasting difficulty (Kumar *et al.*, 2021d; Mian *et al.*, 2020) also makes organizations cast doubt on the implementation of smart manufacturing.

Scalability issue: To implement smart manufacturing, all devices and organizations will be connected, which will create a massive amount of data that must be stored, so the scalability of the system must be guaranteed to prevent disruption and allow stakeholders to access the information quickly and easily (Abdul-Hamid *et al.*, 2020; Brichni and Guedria, 2018).

Security and privacy issues: Implementing smart manufacturing will create changes in data access that will raise concerns about privacy intrusion (Nasrollahi and Ramezani, 2020; Sengupta *et al.*, 2020; Singh and Misra, 2021) and security, which is a barrier that will create considerable resistance in the members of the organization. Partners are not sure how to maintain the data, which will lead to mistrust between partners (Dai *et al.*, 2020; Fernandez-Carames and Fraga-Lamas, 2019; Laeeq and Shamsi, 2015; Matt *et al.*, 2020; Müller *et al.*, 2018; Singh and Misra, 2021). In addition to organizational members and partners, customers are also concerned about losing control of their information (Ghadge *et al.*, 2020; Majumdar *et al.*, 2021; Singh and Misra, 2021; Teck *et al.*, 2019). As such, privacy-related concerns will make everyone more reluctant to share information (Fernandez-Carames and Fraga-Lamas, 2019; Luthra and Mangla, 2018).

Structural issue: The organizational structure should be designed following the organization's goals to be improved in line with those goals in case of any changes. And if changes are made, it should be improved following those changes. Therefore, to implement smart manufacturing, the existing organizational structure must also be changed. The current organizational structure is unsuitable for the implementation of smart manufacturing (Kumar *et al.*, 2021c; Orzes *et al.*, 2018; Yang *et al.*, 2018) and requires continuous design and deployment (Ajmera and Jain, 2019; Brichni and Guedria, 2018; Kumar *et al.*, 2021b). In smart manufacturing, due to autonomy and self-control, the authority should largely be delegated (Kumar *et al.*, 2020a; Matt *et al.*, 2020) and this may make managers reluctant.

Unclear I 4.0 contributions and benefits: For the implementation of each project, the benefits and costs should be weighed, and practical, appropriate action should be taken. However, a lack of awareness of the economic benefits of the digitization of production (Kukharuk and Gavrysh, 2019; Matt *et al.*, 2020; Ozkan-Ozen *et al.*, 2020; Raj *et al.*, 2020) and of the contribution of the fourth industry revolution (Matt *et al.*, 2020; Raj *et al.*, 2020; Satyro *et al.*, 2019) can be seen. As a result, the organization's managers and decision-makers will have doubts about the implementation.

Weak interoperability: With smart manufacturing and the use of new technologies, some changes in cooperation and relationships between manpower, machines, resources and partners have also been made, but there are no new methods concerning interoperability and communication (Brichni and Guedria, 2018; Cugno *et al.*, 2021). Several factors, including resistance among the members of the organization, have prevented the system from adapting to the new conditions, whereas the implementation of smart manufacturing requires maximum coordination (Klein *et al.*, 2018; Matt *et al.*, 2020).

Weak IT infrastructure and smart facilities: In a manufacturing system, devices, machines and equipment must be equipped with smart technologies. Therefore, the immaturity of technology (Bécue *et al.*, 2021; Matt *et al.*, 2020; Mian *et al.*, 2020), lack of gradual updating of technologies (Fernandez-Carames and Fraga-Lamas, 2019; Kumar *et al.*, 2021b; Micheler *et al.*, 2019; Raj *et al.*, 2020; Teck *et al.*, 2019), lack of manufacturing equipment for Industry 4.0 (Halse and Jæge, 2019; Luthra and Mangla, 2018) and limitations of device resources (Bécue *et al.*, 2021; Choudhary *et al.*, 2020; Orzes *et al.*, 2018; Qarabsh *et al.*, 2020; Yu *et al.*, 2020a; Zhao *et al.*, 2019) will be significant barriers to moving towards smart manufacturing. The internet is vital in Industry 4.0 and forms the basis of many relationships and actions, so weak Internet infrastructures (Kamble *et al.*, 2018b; Ozkan-Ozen *et al.*, 2020) also prevent smart manufacturing (Sjödin *et al.*, 2018):

RQ2. Classification of identified barriers

After identifying the barriers to implementing smart manufacturing, the next step is assigning them to the specified categories. As mentioned earlier (see subsection 4.1), we divided the barriers into two general categories (managerial factors and executive infrastructure). Each of the two categories includes subcategories mentioned in Table 1 and Figure 4.

Based on the definitions of each of these barriers provided by previous research, these barriers can be placed in the above categorization. Table 4 shows this classification:

RQ3. Determining the component of the technology associated with each barrier

As previously mentioned, technology encompasses four main components: *technoware* (tools and machines), *humanware* (manpower), *infoware* (experiences, knowledge and creativity) and *orgaware* (organizing and managing operations within technological activities). To effectively address barriers hindering the implementation of smart manufacturing, it is crucial to identify which part of the technology each barrier is associated with. This understanding enables managers to adopt tailored strategies corresponding to the source of the barrier, thus enhancing implementation efforts.

Despite an extensive review of selected articles, no study has thoroughly examined the relationship between technology components and barriers to smart manufacturing

Barrier groups	Dimensions	Barriers
Executive infrastructures	Concern on marketing	Market issues
	Concern about data management	Scalability Big data issues
	Concern about device connectivity	Lack of technology integration Weak IT infrastructure and smart facilities
	Concern about security and privacy	Security and privacy issues
Managerial factors	Analysis and strategy	Unclear I 4.0 contributions and benefits
	Planning and implementation	Lack of standardization Legal issue High costs
	Cooperating and network	Weak interoperability
	Business model	Lack of new business models
	Human resources	Lack of skilled and trained workforce for I4.0
	Change and leadership	Structural issues Lack of adoptability

Source: Authors' own work

Table 4. Classification of identified barriers

implementation, highlighting a significant gap in existing literature. In the following section, we determine the technology component related to each barrier based on definitions and explanations provided in the selected articles.

The challenge of a skilled and trained workforce for Industry 4.0, as evidenced by studies (Al-Salman and Salih, 2019; Kumar *et al.*, 2021b; Murmura and Bravi, 2018), is clearly associated with the *humanware* component. Similarly, Employee Fear and Resistance, supported by research (Aggarwal *et al.*, 2019), also align with the human component of technology due to resistance stemming from unfamiliarity with new technologies.

Furthermore, High Cost, as indicated in studies (Choudhary *et al.*, 2020; Contador *et al.*, 2020), is partly related to *humanware*, particularly regarding staff training costs. However, it also intersects with technoware, as substantial expenses are directed toward manufacturing system changes and machinery upgrades (Aggarwal *et al.*, 2019; Choudhary *et al.*, 2020).

Weak IT infrastructure and smart facilities constitute *technoware* barriers, reflecting equipment deficiencies. Lack of Standardization, addressing device heterogeneity and compliance issues (Brichni and Guedria, 2018; Faheem *et al.*, 2018; Goh *et al.*, 2020) also falls within *technoware*-related barriers.

In addition, lack of technology integration, impeding communication and coordination among units or organizations (Fuller *et al.*, 2020; Moktadir *et al.*, 2018), primarily aligns with *technoware*. However, it also relates to orgaware, given its impact on coordination and communication efficiency.

Lack of adaptability, stemming from managerial support and strategic deficiencies (Aggarwal *et al.*, 2019; Matt *et al.*, 2020), pertains to orgaware. Similarly, the absence of new business models, crucial for organizational goals and strategies (Abdul-Hamid *et al.*, 2020; Kumar *et al.*, 2021b), also correlates with *orgaware*.

Legal issues and market issues, affecting management activities and organizational dynamics (Aggarwal *et al.*, 2019; Bajic *et al.*, 2021), are categorized under *orgaware* due to their influence on organizational management and market positioning.

Structural issues affecting organizational alignment with smart manufacturing goals (Kumar *et al.*, 2021c; Orzes *et al.*, 2018) fall under *orgaware*, impacting workforce autonomy and self-control.

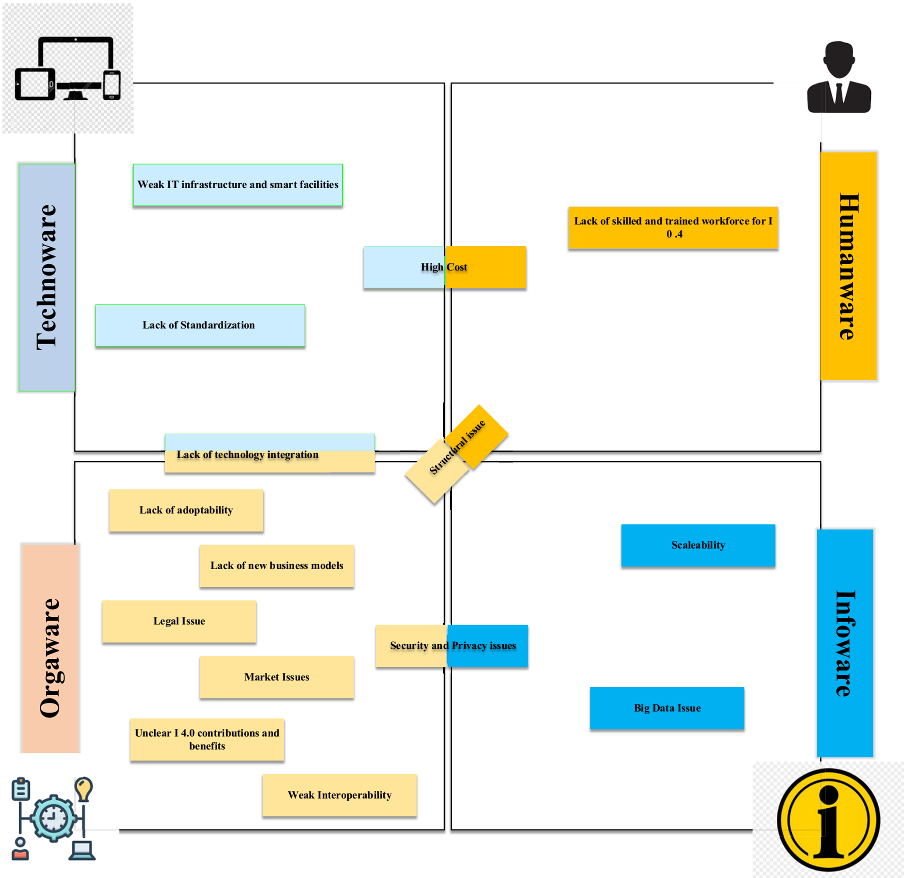
Unclear I4.0 contributions and benefits, hindering cost-effectiveness analysis (Kukharuk and Gavrysh, 2019; Matt *et al.*, 2020), are associated with *orgaware*. Similarly, Weak Interoperability, affecting communication and collaboration management (Brichni and Guedria, 2018; Fernandez-Carames and Fraga-Lamas, 2019), also falls under orgaware.

Security and privacy issues, resulting in stakeholder resistance due to data insecurity fears (Fernandez-Carames and Fraga-Lamas, 2019; Obiso *et al.*, 2019), relate to *orgaware* and *infoware*, given their impact on data access and management.

Furthermore, Big data issues and data issues, addressing data analysis and management challenges (Ahmed *et al.*, 2019), primarily align with *infoware*, considering their connection to data management difficulties. Similarly, scalability issues, necessitating system scalability for large data volumes (Abdul-Hamid *et al.*, 2020; Ghadge *et al.*, 2020), are related to *infoware* (see Figure 10):

RQ4. Determining the stakeholder associated with each barrier

Among the selected studies, only Fraga-Lamas and Fernández-Caramés (2019) dealt with the relationship between challenges and stakeholders, specifically in the automotive industry. They consider stakeholders such as car, ridesharing or ride-hailing passengers car ridesharing or ride-hailing passengers, car entrepreneurs, tech companies, dealer/retailers, OEM/car manufacturers, insurance companies, independent repair shops, aftermarket, governments and public organizations, financial institutions, telecom and tech companies, scrappage/recycle,



Source: Authors own work

Figure 10.
Barriers and their related technology

academia, car owners and lenders, fleet management companies. Then, they assigned the blockchain challenges resulting from reviewing the literature to each stakeholder.

In other selected studies, this type of investigation has not been conducted directly, and only based on the definitions and explanations of each barrier its related stakeholders can be found.

As mentioned earlier, manufacturing systems include employees, management, customers, government, shareholders and competitors.

The adoption of smart manufacturing brings forth various challenges, each intersecting with different stakeholders and technological aspects. Let us delve into these barriers and their associated stakeholders:

Big data issue: The substantial volume of data within smart manufacturing systems poses challenges in collection, analysis and management, impacting stakeholders (Fuller *et al.*, 2020; Khan *et al.*, 2020a; Yu *et al.*, 2020a, 2020b). Difficult data access further exacerbates this barrier, affecting shareholders who rely on data within the manufacturing system (Micheler *et al.*, 2019; M. Sharma and Sehrawat, 2020).

High costs: The significant operating and initial investment costs deter managers from embracing smart manufacturing (Bajic *et al.*, 2021; Chauhan *et al.*, 2021), influencing both management decisions and shareholder interests.

Lack of adaptability: Managerial resistance due to fear of failure hampers smart manufacturing adoption (Aggarwal *et al.*, 2019; Matt *et al.*, 2020). Lack of government support further impedes adaptability, impacting both management and employee readiness (Abbasi and Kamal, 2020; Machado *et al.*, 2019).

Lack of new business models: Stakeholders, including management and customers, play pivotal roles in determining organizational strategies aligned with customer needs (Mian *et al.*, 2020).

Lack of skilled workforce for I4.0: Employees and management are key stakeholders affected by the shortage of skills and training needed for smart environments (Al-Salman and Salih, 2019; Kamble *et al.*, 2019).

Lack of standardization: Communication complexities arising from differing device standards impact management efficiency (Brichni and Guedria, 2018; Faheem *et al.*, 2018).

Lack of technology integration: Disrupted connectivity between devices, units and organizations challenges system management (Pradhan and Agwa-Ejon, 2018; Rauch *et al.*, 2019).

Legal issues: Inadequate regulations complicate data management and organizational activities, affecting management, employees and stakeholders (Aggarwal *et al.*, 2019; Dalzochio *et al.*, 2020).

Market issues: Competitive pressures and customer resistance to change impact market dynamics and organizational strategies (Bajic *et al.*, 2021; Contador *et al.*, 2020).

Scalability issue: Challenges in managing large data volumes disrupt data accessibility and management (Abdul-Hamid *et al.*, 2020; Mazzei *et al.*, 2020).

Security and privacy issues: Concerns over data security and privacy impact all stakeholders, including management, employees and customers (Ghadge *et al.*, 2020; Majumdar *et al.*, 2021; Teck *et al.*, 2019).

Structural issues: Organizational structure adaptation and autonomy delegation challenge both management and employees (Ajmera and Jain, 2019; Brichni and Guedria, 2018; Kumar *et al.*, 2020a; Matt *et al.*, 2020).

Unclear I4.0 contributions and benefits: Ambiguity regarding the benefits of smart manufacturing affects stakeholder management and shareholder interests (Matt *et al.*, 2020; Ozkan-Ozen *et al.*, 2020).

Weak interoperability: Resistance to cooperation among workforce, machines and partners due to changing relationships disrupts organizational dynamics, impacting employees, managers and shareholders (Brichni and Guedria, 2018; Cugno *et al.*, 2021).

Weak IT infrastructure and smart facilities: The absence of robust internet platforms hinders successful deployment, with implications for government and management stakeholders (Bakhtari *et al.*, 2021; Stentoft *et al.*, 2020). See Table 5.

After reviewing selected articles, it becomes evident that a significant gap in the current literature concerning the barriers to smart manufacturing remains unaddressed. This gap involves identifying stakeholders capable of influencing barriers to smart manufacturing implementation. Moreover, it is imperative to discern which stakeholders are associated with each barrier, as they play a crucial role in overcoming these barriers. Despite its importance, the only study to delve into stakeholders is by Fraga-Lamas and Fernández-Caramés (2019), focusing on stakeholders related to blockchain challenges in the automotive industry. However, it is crucial to note that these challenges and stakeholders are specific to blockchain within the automotive sector and cannot be generalized to smart manufacturing and other industries.

Table 5. Stakeholders associated with each resource based on selected articles

Barriers	Employees	Management	Customers	Government	Shareholders	Competitors
Big data issues		X			X	
High costs		X			X	
Lack of adaptability	X	X		X		
Lack of new business models		X	X			
Lack of skilled and trained workforce for I4.0	X	X				
Lack of standardization		X				
Lack of technology integration		X				
Legal issue	X	X				X
Market issues			X			X
Scalability issue		X				
Security and privacy issues	X	X	X			
Structural issue	X	X				
Unclear I 4.0 contributions and benefits		X			X	
Weak interoperability	X	X			X	
Weak IT infrastructure and smart facilities		X		X		

Source: Authors' own work

The stakeholders mentioned earlier are derived from definitions and explanations provided for each barrier in the selected research. However, it is evident that the roles of some stakeholders in various barriers have been overlooked. For instance, in the lack of adaptability barrier, besides employees, management and government, other influential stakeholders include competitors, customers and shareholders. Promoting smart manufacturing among competitors can drive organizations to adapt smart manufacturing practices to maintain competitiveness. Moreover, customer acceptance levels significantly motivate organizations to embrace smart manufacturing. Shareholders, as primary decision-makers within organizations, also wield significant influence. Therefore, scholars interested in studying barriers to smart manufacturing promotion should consider this gap in stakeholder identification.

6. Discussion

The findings related to research questions 3 and 4 are deeply intertwined and shed light on the complex dynamics of smart manufacturing implementation.

The research reveals that barriers to smart manufacturing implementation are closely tied to specific components of technology. For instance, barriers like a lack of skilled workforce and employee fear/resistance are primarily associated with the humanware component, whereas barriers like high costs and weak IT infrastructure fall under the technoware domain. Similarly, barriers such as lack of adaptability and unclear I4.0 contributions and benefits are predominantly related to orgaware, emphasizing the importance of organizational management and strategy. These findings underline the necessity of identifying the technological aspect underlying each barrier to devise targeted strategies for implementation.

The study also elucidates the stakeholders affected by various barriers in smart manufacturing adoption. Stakeholders encompass a broad spectrum, including employees, management, customers, government, shareholders and competitors. Each barrier intersects with different stakeholders, influencing their decisions, behaviors and interests. For example, barriers like high costs impact both management decisions and shareholder interests, whereas challenges like lack of skilled workforce predominantly affect employees and management. These findings emphasize the intricate network of stakeholders involved in smart manufacturing implementation and highlight the need to consider their perspectives and concerns.

We can discern a symbiotic relationship between technology components, barriers and stakeholders in smart manufacturing adoption by linking these findings. Understanding which technological aspect underlies each barrier allows for tailored strategies that address specific challenges, thereby facilitating smoother implementation. Moreover, recognizing the diverse stakeholders affected by these barriers enables stakeholders to align their interests and collaborate effectively toward overcoming barriers. Thus, the findings underscore the importance of an integrated approach that considers both technological and stakeholder dimensions in advancing smart manufacturing initiatives.

7. Managerial implications

The findings of this study provide some practical strategies for the managers. Implementing these strategies capitalizes on the dynamic relationship among technology components, barriers and stakeholders, fostering the seamless integration of smart manufacturing practices within organizations. Companies can effectively navigate the intricacies of smart manufacturing adoption and maximize its benefits by directly tackling the challenges unearthed through this research and involving key stakeholders. In the following, we discuss some of the strategies:

Integrated training programs: Develop comprehensive training programs to enhance the workforce's skills and knowledge (humanware). These programs should cover both technical aspects of smart manufacturing technologies and soft skills to mitigate employee fear and resistance.

Investment in technology infrastructure: Allocate resources to upgrade and maintain robust IT infrastructure and smart facilities (*technoware*). This includes ensuring reliable internet connectivity, upgrading machinery and tools and implementing advanced data management systems to handle large volumes of data.

Standardization initiatives: Collaborate with industry stakeholders to establish and adhere to standardized protocols and technologies (*technoware*). This will streamline communication and interoperability between different devices and systems, reducing complexities and barriers.

Change management strategies: Implement change management strategies to foster organizationaladaptability (*orgaware*). This involves clear communication of goals and benefits, involving employees in decision-making and providing adequate support and resources for transition.

Government policy support: Advocate for supportive government policies and regulations that facilitate smart manufacturing adoption (*orgaware*). This includes incentives for investment in technology, rules promoting data security and privacy and initiatives to bridge the digital skills gap.

Market awareness campaigns: Conduct market awareness campaigns to educate customers about the benefits of smart manufacturing (*orgaware*). Highlighting the value proposition and competitive advantages can incentivize customer acceptance and drive market demand.

Strategic Partnerships: Forge strategic partnerships with suppliers, customers and industry peers to address common challenges and share resources (*orgaware*). Collaborative efforts can help overcome barriers such as high costs and interoperability issues.

Data management solutions: Implement advanced data management solutions and analytics tools to address Big data challenges (*infoware*). This includes investing in data processing and analysis technologies to derive actionable insights and improve decision-making processes.

Privacy and security measures: Prioritize data security and privacy measures to alleviate stakeholder concerns (*infoware*). Implement robust cybersecurity protocols, encryption techniques and access controls to safeguard sensitive information and build trust among stakeholders.

Continuous improvement culture: Foster a culture of continuous improvement and innovation within the organization (*orgaware*). Encourage experimentation, knowledge sharing and feedback loops to identify and address emerging barriers and opportunities in smart manufacturing implementation.

These strategies leverage the interplay between technology components, barriers and stakeholders to facilitate the successful adoption of smart manufacturing practices. Organizations can navigate complexities and unlock the full potential of smart manufacturing initiatives by addressing the specific challenges identified in the research findings and engaging relevant stakeholders.

8. Conclusion, future research and limitation

The widespread integration of smart manufacturing technologies presents an impetus for organizational adaptation. However, various factors may hinder its implementation. This study aimed to identify and classify barriers to smart manufacturing adoption through a SLR encompassing 133 relevant studies from 1993 to November 2021. This review revealed 15 barriers categorized into managerial factors and technological infrastructures, a novel classification compared to previous studies solely focusing on technological barriers. This classification offers managers insights into addressing barriers at different stages of implementation, enabling a smoother transition to smart manufacturing practices.

Each identified barrier corresponds to a specific technology component, facilitating the formulation of targeted strategies for barrier removal. In addition, pinpointing the influential stakeholders associated with each barrier is instrumental. Stakeholders play a pivotal role in decision-making and problem-solving within organizations, thus their identification aids in devising effective strategies for smart manufacturing implementation.

Despite the study's contributions, several research gaps were identified, offering avenues for future exploration. First, while numerous studies have identified barriers, there remains a dearth of comprehensive strategies for overcoming them. Future research could focus on devising tailored strategies to address these barriers effectively. Second, determining the stakeholders impacted by or influencing barriers remains underexplored. Investigating stakeholder dynamics could provide valuable insights into decision-making processes and organizational goal achievement. Finally, further exploration into the relationship between technology components and barriers could inform targeted intervention strategies for barrier mitigation.

However, this study has limitations, including language restrictions and potential omission of relevant non-English studies. In addition, the study's reliance on periodic updates may have overlooked recent publications, warranting ongoing research in this area to address emerging challenges and opportunities in smart manufacturing implementation.

Note

1. A Boolean search is a query technique that uses Boolean Logic to connect individual keywords or phrases within a single query.

References

Abbasi, A. and Kamal, M.M. (2020), "Adopting industry 4.0 technologies in citizens' electronic-engagement considering sustainability development", European, Mediterranean, and Middle Eastern Conference, Springer.

Abdirad, M. and Krishnan, K. (2020), "Industry 4.0 in logistics and supply chain management: a systematic literature review", *EMJ-Engineering Management Journal*, Vol. 33 No. 3, pp. 1-15, doi: 10.1080/10429247.2020.1783935.

Abdul-Hamid, A.Q., *et al.* (2020), "Impeding challenges on industry 4.0 in circular economy: palm oil industry in Malaysia", *Computers and Operations Research*, Vol. 123, p. 105052, doi: 10.1016/j.cor.2020.105052.

Ada, N., *et al.* (2021), "Analyzing barriers of circular food supply chains and proposing industry 4.0 solutions", *Sustainability (Switzerland)*, Vol. 13 No. 12, pp. 1-29.

Aggarwal, A., Gupta, S. and Ojha, M.K. (2019), "Evaluation of key challenges to industry 4.0 in Indian context: a DEMATEL approach", *Advances in Industrial and Production Engineering*, Springer, Singapore, pp. 387-396, doi: 10.1007/978-981-13-6412-9.

Ahmed, E.M. (2020), "COVID-19 implications on IsDB member countries sustainable digital economies", *International Journal of Innovation and Knowledge Management in Middle East and North Africa*, Vol. 8 Nos 1/2, pp. 11-37.

Ahmed, A.I.A., et al. (2019), "Service management for IOT: requirements, taxonomy, recent advances and open research challenges", *IEEE Access*, Vol. 7, pp. 155472-1588.

Ajmera, P. and Jain, V. (2019), "Modelling the barriers of health 4.0–the fourth healthcare industrial revolution in India by TISM", *Operations Management Research*, Vol. 12 Nos 3/4, pp. 129-145.

Alaa, M., Zaidan, A.A., Zaidan, B.B., Talal, M. and Kiah, M.L.M. (2017), "A review of smart home applications based on internet of things", *Journal of Network and Computer Applications*, Vol. 97, pp. 48-65.

Alaloul, W.S., Liew, M.S., Zawawi, N.A.W.A. and Kennedy, I.B. (2020), "Industrial revolution 4.0 in the construction industry: challenges and opportunities for stakeholders", *Ain Shams Engineering Journal*, Vol. 11 No. 1, pp. 225-230.

Alraja, M.N., Alshubiri, F., Khashab, B.M. and Shah, M. (2023), "The financial access, ICT trade balance and dark and bright sides of digitalization nexus in OECD countries", *Eurasian Economic Review*, Vol. 13 No. 2, pp. 1-33.

Alromaihi, S., Elmedany, W. and Balakrishna, C. (2018), "Cyber security challenges of deploying IoT in smart cities for healthcare applications", Proceedings – 2018 IEEE 6th International Conference on Future Internet of Things and Cloud Workshops, W-FiCloud 2018, pp. 140-145.

Al-Salman, H.I. and Salih, M.H. (2019), "A review cyber of industry 4.0 (cyber-physical systems (CPS), the internet of things (IoT) and the internet of services (IoS)): components, and security challenges", *Journal of Physics: Conference Series*, Vol. 1424 No. 1, pp. 0-6.

Alshubiri, F. (2022), "The effect of saving and capital expansion on financial and technological development in GCC countries", *Technological and Economic Development of Economy*, Vol. 28 No. 1, pp. 1-25.

ALshubiri, F., ALmaashani, A.A. and Thuaar, S.M. (2023), "The impact of the digital economy paradigm on the productivity and monetary system of Oman", *Journal of Science and Technology Policy Management*, Vol. 14 No. 5, pp. 830-858.

Amjad, M.S., Rafique, M.Z., Hussain, S. and Khan, M.A. (2020), "A new vision of LARG manufacturing —a trail towards industry 4.0", *CIRP Journal of Manufacturing Science and Technology*, Vol. 31 No. 2019, pp. 377-393.

Bag, S., Telukdarie, A., Pretorius, J.H.C. and Gupta, S. (2018), "Industry 4.0 and supply chain sustainability: framework and future research directions", *Benchmarking: An International Journal*.

Bag, S., et al. (2021), "Modeling barriers of digital manufacturing in a circular economy for enhancing sustainability", *International Journal of Productivity and Performance Management*, Vol. 71 No. 3.

Bajic, B., Rikalovic, A., Suzic, N. and Piuri, V. (2021), "Industry 4.0 implementation challenges and opportunities: a managerial perspective", *IEEE Systems Journal*, Vol. 15 No. 1, pp. 546-559.

Bakhtari, A.R., et al. (2020), "Industry 4.0 implementation challenges in manufacturing industries: an interpretive structural modelling approach", *Procedia Computer Science*, Vol. 176, pp. 2384-93, doi: 10.1016/j.procs.2020.09.306.

Bakhtari, A.R., Waris, M.M., Sanin, C. and Szczerbicki, E. (2021), "Evaluating industry 4.0 implementation challenges using interpretive structural modeling and fuzzy analytic hierarchy process", *Cybernetics and Systems*, Vol. 52 No. 5, pp. 1-29, doi: 10.1080/01969722.2020.1871226.

Balas, P.K., Obaid, A.J., Cengiz, K., Khanna, A. and Emilia, V. (2022), "210 A fusion of artificial intelligence and internet of things for emerging cyber systems", available at: https://link.springer.com/10.1007/978-3-030-76653-5.

Barik, M.S., Sengupta, A. and Mazumdar, C. (2017), "Managing the cyber security life-cycle of smart cities", *Smart Cities: Foundations, Principles, and Applications*, Wiley, pp. 391-407.

Batagelj, V. (1989), "Efficient algorithms for citation network analysis ArXiv: Cs/0309023v1 [Cs. DL] 14 Sep 2003", pp. 1-27.

Bécue, A., Praça, I. and Gama, J. (2021), *Artificial Intelligence Review Artificial Intelligence, Cyber-Threats and Industry 4.0: Challenges and Opportunities*, Springer Netherlands, doi: 10.1007/s10462-020-09942-2.

Benotsmane, R., Kovács, G. and Dudás, L. (2019), "Economic, social impacts and operation of smart factories in industry 4.0 focusing on simulation and artificial intelligence of collaborating robots", *Social Sciences*, Vol. 8 No. 5, p. 143.

Birkel, H. and Müller, J.M. (2021), "Potentials of industry 4.0 for supply chain management within the triple bottom line of sustainability – a systematic literature review", *Journal of Cleaner Production*, Vol. 289, p. 125612, doi: 10.1016/j.jclepro.2020.125612.

Bogle, I.D.L. (2017), "A perspective on smart process manufacturing research challenges for process systems engineers", *Engineering*, Vol. 3 No. 2, pp. 161-165, doi: 10.1016/J.ENG.2017.02.003.

Brichni, M. and Guedria, W. (2018), 11230 LNCS lecture notes in computer science (including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics), *Data Analytics Challenges in Industry 4.0: A Case-Based Approach*, Springer International Publishing, doi: 10.1007/978-3-030-02671-4_12.

Bueno, A., Godinho Filho, M. and Frank, A.G. (2020), "Smart production planning and control in the industry 4.0 context: a systematic literature review", *Computers and Industrial Engineering*, Vol. 149, p. 106774, doi: 10.1016/j.cie.2020.106774.

Carlucci, D., et al. (2018), "A holistic conception of sustainable banking: adding value with fuzzy cognitive mapping", *Technological and Economic Development of Economy*, Vol. 24 No. 4, pp. 1303-22.

Chauhan, C., Singh, A. and Luthra, S. (2021), "Barriers to industry 4. 0 adoption and its performance implications: an empirical investigation of emerging economy", *Journal of Cleaner Production*, Vol. 285, p. 124809, doi: 10.1016/j.jclepro.2020.124809.

Chong, K.P., VanLandingham, M.R. and Sung, L. (2002), "Advances in materials and mechanics", *Advances in Building Technology*, Elsevier Science.

Choudhary, T., Virmani, C. and Juneja, D. (2020), "Convergence of blockchain and IoT: an edge over technologies", *846 Studies in Computational Intelligence*, Springer International Publishing, doi: 10.1007/978-3-030-24513-9_17.

Cioffi, R., et al. (2020), "Smart manufacturing systems and applied industrial technologies for a sustainable industry: a systematic literature review", *Applied Sciences*, Vol. 10 No. 8, pp. 1-22.

Contador, J.C., Satyro, W.C., Contador, J.L. and Spinola, M. D M. (2020), "Flexibility in the Brazilian Industry 4.0: challenges and opportunities", *Global Journal of Flexible Systems Management*, Vol. 21 No. S1, pp. 15-31.

Cugno, M., Castagnoli, R. and Büchi, G. (2021), "Openness to Industry 4.0 and performance: the impact of barriers and incentives", *Technological Forecasting and Social Change*, Vol. 168, p. 120756, doi: 10.1016/j.techfore.2021.120756.

Cui, Y., Kara, S. and Chan, K.C. (2020), "Manufacturing big data ecosystem: a systematic literature review", *Robotics and Computer-Integrated Manufacturing*, Vol. 62, p. 101861, doi: 10.1016/j.rcim.2019.101861.

Cui, Y., Liu, W., Rani, P. and Alrasheedi, M. (2021), "Internet of things (IoT) adoption barriers for the circular economy using pythagorean fuzzy SWARA-CoCoSo Decision-Making approach in the manufacturing sector", *Technological Forecasting and Social Change*, Vol. 171, p. 120951, doi: 10.1016/j.techfore.2021.120951.

Dai, H.N., et al. (2020), "Big data analytics for manufacturing internet of things: opportunities, challenges and enabling technologies", *Enterprise Information Systems*, Vol. 14 Nos 9/10, pp. 1279-1303, doi: 10.1080/17517575.2019.1633689.

Dalzochio, J., et al. (2020), "Machine learning and reasoning for predictive maintenance in industry 4.0: current status and challenges", *Computers in Industry*, Vol. 123, p. 103298, doi: 10.1016/j.compind.2020.103298.

de Vass, T., Shee, H. and Miah, S. (2021), "IoT in supply chain management: opportunities and challenges for businesses in early industry 4.0 context", *Operations and Supply Chain Management: An International Journal*, Vol. 14 No. 2, pp. 148-161.

Demirkesen, S. and Tezel, A. (2021), "Investigating major challenges for Industry 4.0 adoption among construction companies", *Engineering, Construction and Architectural Management*.

Dikhanbayeva, D., et al. (2021), "Critical factors of Industry 4.0 implementation in an emerging country: empirical study", *Future Internet*, Vol. 13 No. 6.

Egger, J. and Masood, T. (2019), "Augmented reality in support of intelligent manufacturing – a systematic literature review", *Computers and Industrial Engineering*, Vol. 185, p. 106195, doi: 10.1016/j.cie.2019.106195.

Etemadi, N., Van Gelder, P. and Strozzi, F. (2021), "An ism modeling of barriers for blockchain/distributed ledger technology adoption in supply chains towards cybersecurity", *Sustainability (Switzerland)*, Vol. 13 No. 9, p. 4672.

Faheem, M., et al. (2018), "Smart grid communication and information technologies in the perspective of Industry 4.0: opportunities and challenges", *Computer Science Review*, Vol. 30, pp. 1-30, doi: 10.1016/j.cosrev.2018.08.001.

Falco, E. and Kleinhans, R. (2018), "Beyond technology: identifying local government challenges for using digital platforms for citizen engagement", *International Journal of Information Management*, Vol. 40, pp. 17-20.

Fernandez-Carames, T.M. and Fraga-Lamas, P. (2019), "A review on the application of blockchain to the next generation of cybersecure industry 4.0 smart factories", *IEEE Access*, Vol. 7 No. c, pp. 45201-45218.

Foukalas, F., et al (2019), "Dependable wireless industrial IoT networks: recent advances and open challenges", Proceedings of the European Test Workshop, 2019-May.

Fraga-Lamas, P. and Fernández-Caramés, T.M. (2019), "A review on blockchain technologies for an advanced and cyber-resilient automotive industry", *IEEE Access*, Vol. 7 No. c, pp. 17578-17598.

Frank, A.G., Dalenogare, L.S. and Ayala, N.F. (2019), "Industry 4.0 technologies: implementation patterns in manufacturing companies", *International Journal of Production Economics*, Vol. 210, pp. 15-26.

Freeman, R.E. (1984), "Corporate views of the public interest".

Fuller, A., Fan, Z., Day, C. and Barlow, C. (2020), "Digital twin: enabling technologies, challenges and open research", *IEEE Access*, Vol. 8, pp. 108952-108971.

Gallab, M., Bouloiz, H., Kebe, S.A. and Tkiouat, M. (2021), "Opportunities and challenges of the Industry 4.0 in industrial companies: a survey on Moroccan firms", *Journal of Industrial and Business Economics*, Vol. 48 No. 3, pp. 413-439, doi: 10.1007/s40812-021-00190-1.

Gamble, J.R., Clinton, E. and Díaz-Moriana, V. (2021), "Broadening the business model construct: exploring how family-owned SMEs co-create value with external stakeholders", *Journal of Business Research*, Vol. 130, pp. 646-657, doi: 10.1016/j.jbusres.2020.03.034.

Gamil, Y., A. Abdullah, M., Abd Rahman, I. and Asad, M.M. (2020), "Internet of things in construction industry revolution 4.0: Recent trends and challenges in the Malaysian context", *Journal of Engineering, Design and Technology*, Vol. 18 No. 5, pp. 1091-1102.

Ghadge, A., Er Kara, M., Moradlou, H. and Goswami, M. (2020), "The impact of Industry 4.0 implementation on supply chains", *Journal of Manufacturing Technology Management*, Vol. 31 No. 4, pp. 669-686.

Ghahramani, M., et al (2020), "AI-Based modeling and data-driven evaluation for smart manufacturing processes", arXiv.

Goh, G.D., Sing, S.L. and Yeong, W.Y. (2020), *Artificial Intelligence Review A Review on Machine Learning in 3D Printing: Applications, Potential, and Challenges*, Springer Netherlands, doi: 10.1007/s10462-020-09876-9.

Goswami, M. and Daultani, Y. (2021), "Make-in-India and industry 4.0: technology readiness of select firms, barriers and socio-technical implications", *The TQM Journal*, ahead-of-print.

Guelzim, T., Obaidat, M.S. and Sadoun, B. (2016), *Smart Cities and Homes: Key Enabling Technologies Introduction and Overview of Key Enabling Technologies for Smart Cities and Homes*, Elsevier, doi: 10.1016/B978-0-12-803454-5/00001-8.

Gupta, R., et al. (2020), "Smart contract privacy protection using AI in cyber-physical systems: tools, techniques and challenges", *IEEE Access*, Vol. 8, pp. 24746-24772.

Gurzawska, A., Mäkinen, M. and Brey, P. (2017), "Implementation of responsible research and innovation (RRI) practices in industry: Providing the right incentives", *Sustainability (Switzerland)*, Vol. 9 No. 10, pp. 1-26.

Gustafsson, H., Hancock, D.J. and Jean, C. (2014), "Describing citation structures in sport burnout literature: a citation network analysis", *Psychology of Sport and Exercise*, Vol. 15 No. 6, pp. 620-626.

Haines, J.D. and Sharif, N.M. (2006), "A framework for managing the sophistication of the components of technology for global competition", *Competitiveness Review: An International Business Journal Incorporating Journal of Global Competitiveness*, Vol. 16 No. 2, pp. 106-121.

Halse, L.L. and Jæge, B. (2019), "Operationalizing Industry 4.0: understanding barriers of industry 4.0 and circular economy", *IFIP International Conference on Advances in Production Management Systems*, Springer, *Charm*, pp. 135-142.

Hizam-Hanafiah, M., Soomro, M.A. and Abdullah, N.L. (2020), "Industry 4.0 readiness models: a systematic literature review of model dimensions", *Information (Switzerland)*, Vol. 11 No. 7, pp. 1-13.

Hummon, N.P. and Dereian, P. (1989), "Connectivity in a citation network: the development of DNA theory", *Social Networks*, Vol. 11 No. 1, pp. 39-63.

Jamai, I., Ben Azzouz, L. and Saidane, L.A. (2020), "Security issues in Industry 4.0", 2020 International Wireless Communications and Mobile Computing, IWCMC 2020, pp. 481-488.

Juet, E. (2014), "The regulation by law of nanosciences and nanotechnologies", *Environmental Impact of Polymers*, Vol. 9781848216, pp. 341-356.

Kamble, S.S., Gunasekaran, A. and Gawankar, S.A. (2018a), "Sustainable industry 4.0 framework: a systematic literature review identifying the current trends and future perspectives", *Process Safety and Environmental Protection*, Vol. 117, pp. 408-425.

Kamble, S.S., Gunasekaran, A. and Sharma, R. (2018b), "Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry", *Computers in Industry*, Vol. 101, pp. 107-119, doi: 10.1016/j.compind.2018.06.004.

Kamble, S.S., Gunasekaran, A., Parekh, H. and Joshi, S. (2019), "Modeling the internet of things adoption barriers in food retail supply chains", *Journal of Retailing and Consumer Services*, Vol. 48, pp. 154-68, doi: 10.1016/j.jretconser.2019.02.020.

Kamble, S.S., Gunasekaran, A., Ghadge, A. and Raut, R. (2020), "A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs- a review and empirical investigation", *International Journal of Production Economics*, Vol. 229, p. 107853.

Karadayi-Usta, S. (2020), "An interpretive structural analysis for industry 4.0 adoption challenges", *IEEE Transactions on Engineering Management*, Vol. 67 No. 3, pp. 973-978.

Khan, A. and Turowski, K. (2016), "A survey of current challenges in manufacturing industry and preparation for Industry 4.0", *Proceedings of the First International Scientific Conference "Intelligent Information Technologies for Industry" (IITI'16)*, pp. 15-26, Springer, *Cham*, pp. 5-6.

Khan, S., Khan, M.I. and Haleem, A. (2020a), "Prioritisation of challenges towards development of smart manufacturing using BWM method", *Internet of Things (IoT)*, Springer, pp. 409-26.

Khan, W.Z., et al. (2020b), "Industrial internet of things: recent advances, enabling technologies and open challenges", *Computers and Electrical Engineering*, Vol. 81, p. 106522.

Klein, M.M., Biehl, S.S. and Friedli, T. (2018), "Barriers to smart services for manufacturing companies – an exploratory study in the capital goods industry", *Journal of Business and Industrial Marketing*, Vol. 33 No. 6, pp. 846-56.

Kukharuk, A. and Gavrysh, J. (2019), "Competitiveness of SMEs in terms of industry 4.0", *International Conference on Creative Business for Smart and Sustainable Growth, CreBUS 2019*, pp. 1-4.

Kumar Hajoary, P. (2023), "Strategic response to industry 4.0–an empirical analysis from a developing country perspective", *Technology Analysis and Strategic Management*, pp. 1-14, doi: 10.1080/09537325.2023.2242520.

Kumar, N., Kumar, G. and Singh, R.K. (2021a), "Analysis of barriers intensity for investment in big data analytics for sustainable manufacturing operations in post-COVID-19 pandemic era", *Journal of Enterprise Information Management*, Vol. 35 No. 1, pp. 179-213.

Kumar, P., Bhamu, J. and HSangwan, K.S. (2021b), "Analysis OfBarriers to industry 4.0 adoption in manufacturing organizations: an ISM approach", 28th CIRP Conference on Life Cycle Engineering 28th CIRP Conference on Life Cycle Engineering Analysis, pp. 85-90.

Kumar, P., Singh, R.K. and Kumar, V. (2021c), "Managing supply chains for sustainable operations in the era of industry 4.0 and circular economy: analysis of barriers", *Resources, Conservation and Recycling*, Vol. 164, p. 105215, doi: 10.1016/j.resconrec.2020.105215.

Kumar, R., Singh, R.K. and Dwivedi, Y.K. (2020a), "Application of industry 4.0 technologies in SMEs for ethical and sustainable operations: analysis of challenges", *Journal of Cleaner Production*, Vol. 275, p. 124063, doi: 10.1016/j.jclepro.2020.124063.

Kumar, S., Suhaib, M. and Asjad, M. (2020b), "Narrowing the barriers to industry 4.0 practices through PCA-Fuzzy AHP-K means", *Journal of Advances in Management Research*, Vol. 18 No. 2, pp. 200-226.

Kumar, V., Vrat, P. and Shankar, R. (2021d), *OPSEARCH Prioritization of Strategies to Overcome the Barriers in Industry 4.0: A Hybrid MCDM Approach*, Springer India, doi: 10.1007/s12597-020-00505-1.

Laeeq, K. and Shamsi, J.A. (2015), "A study of security issues, vulnerabilities, and challenges in the internet of things", *Securing Cyber-Physical Systems*, CRC Press, pp. 221-240.

Lee, Y. (2023), "A systematic review of UTAUT2 constructs ' analysis among MSMEs in Non-OECD countries countries".

Lepekhin, A., Borremans, A., Ilin, I. and Jantunen, S. (2019), "A systematic mapping study on internet of things challenges", Proceedings – 2019 IEEE/ACM 1st International Workshop on Software Engineering Research and Practices for the Internet of Things, SERP4IoT 2019, pp. 9-16.

Li, S., Peng, G.C. and Xing, F. (2019), "Barriers of embedding big data solutions in smart factories: insights from SAP consultants", *Industrial Management and Data Systems*, Vol. 119 No. 5, pp. 1147-1164.

Lu, Y. and Xu, X. (2019), "Cloud-Based manufacturing equipment and big data analytics to enable on-demand manufacturing services", *Robotics and Computer-Integrated Manufacturing*, Vol. 57, pp. 92-102, doi: 10.1016/j.rcim.2018.11.006.

Luthra, S. and Mangla, S.K. (2018), "Evaluating challenges to industry 4.0 initiatives for supply chain sustainability in emerging economies", *Process Safety and Environmental Protection*, Vol. 117, pp. 168-79, doi: 10.1016/j.psep.2018.04.018.

Luthra, S., Garg, D., Kumar Mangla, S. and Singh Berwal, Y.P. (2018), "Analyzing challenges to internet of things (IoT) adoption and diffusion: an Indian context", *Procedia Computer Science*, Vol. 125, pp. 733-39.

Machado, C.G., et al. (2019), "Industry 4.0 readiness in manufacturing companies: challenges and enablers towards increased digitalization", *Procedia CIRP*, Vol. 81, pp. 1113-18, doi: 10.1016/j.procir.2019.03.262.

Majumdar, A., Garg, H. and Jain, R. (2021), "Managing the barriers of industry 4.0 adoption and implementation in textile and clothing industry: interpretive structural model and triple helix framework", *Computers in Industry*, Vol. 125, p. 103372, doi: 10.1016/j.compind.2020.103372.

Mao, S., Wang, B., Tang, Y. and Qian, F. (2019), "Opportunities and challenges of artificial intelligence for green manufacturing in the process industry", *Engineering*, Vol. 5 No. 6, pp. 995-1002, doi: 10.1016/j.eng.2019.08.013.

Marlyana, N., Tontowi, A.E. and Yuniarto, H.A. (2018), "From THIO to THIOCMP: the development of technology assessment concept using technometrics", Proceedings - 12th SEATUC Symposium, SEATUC 2018, p. 4.

Maskuriy, R., et al. (2019), "Industry 4.0 for the construction industry: review of management perspective", *Economies*, Vol. 7 No. 3, pp. 1-14.

Masood, T. and Sonntag, P. (2020), "Industry 4.0: adoption challenges and benefits for SMEs", *Computers in Industry*, Vol. 121, p. 103261, doi: 10.1016/j.compind.2020.103261.

Matt, D.T., Modrák, V. and Zsifkovits, H. (2020), "Industry 4.0 for SMEs: Challenges, opportunities and requirements", *Industry 4.0 for Smes: Challenges, Opportunities and Requirements*, Springer International Publishing.

Mazzei, D., et al. (2020), "A blockchain tokenizer for industrial IOT trustless applications", *Future Generation Computer Systems*, Vol. 105, pp. 432-445, doi: 10.1016/j.future.2019.12.020.

Mian, S.H., et al. (2020), "Adapting universities for sustainability education in Industry 4.0: channel of challenges and opportunities", *Sustainability (Switzerland)*, Vol. 12 No. 15, p. 6100.

Micheler, S., Goh, Y.M. and Lohse, N. (2019), "Innovation landscape and challenges of smart technologies and systems–a European perspective", *Production and Manufacturing Research*, Vol. 7 No. 1, pp. 503-528, doi: 10.1080/21693277.2019.1687363.

Mihovska, A., et al (2015), "Integration of wireless and data technologies for personalized smart applications", *Wireless Telecommunications Symposium* 2015-Janua.

Mittal, S., Khan, M.A., Romero, D. and Wuest, T. (2018), "A critical review of smart manufacturing and industry 4.0 maturity models: implications for small and medium-sized enterprises (SMEs)", *Journal of Manufacturing Systems*, Vol. 49, pp. 194-214, doi: 10.1016/j.jmsy.2018.10.005.

Moghaddam, M., Cadavid, M.N., Kenley, C.R. and Deshmukh, A.V. (2018), "Reference architectures for smart manufacturing: a critical review", *Journal of Manufacturing Systems*, Vol. 49, pp. 215-25.

Mohamed, M.A., Challenger, M. and Kardas, G. (2020), "Applications of model-driven engineering in cyber-physical systems: a systematic mapping study", *Journal of Computer Languages*, Vol. 59, p. 100972.

Moher, D., Liberati, A., Tetzlaff, J. and Altman, D.G. (2009), "Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement", *Annals of Internal Medicine*, Vol. 151 No. 4, pp. 264-269.

Moktadir, M.A., Ali, S.M., Kusi-Sarpong, S. and Ali Shaikh, M.A. (2018), "Assessing challenges for implementing industry 4.0: Implications for process safety and environmental protection", *Process Safety and Environmental Protection*, Vol. 117, pp. 730-741, doi: 10.1016/j.psep.2018.04.020.

Motta, R.C., De Oliveira, K.M. and Travassos, G.H. (2018), "On challenges in engineering IoT software systems", *ACM International Conference Proceeding Series*, pp. 42-51.

Mrugalska, B. and Ahmed, J. (2021), "Organizational agility in Industry 4.0: a systematic literature review", *Sustainability (Switzerland)*, Vol. 13 No. 15, pp. 1-23.

Müller, J.M. (2019), "Assessing the barriers to Industry 4.0 implementation from a workers' perspective", *IFAC-PapersOnLine*, Vol. 52 No. 13, pp. 2189-2194, doi: 10.1016/j.ifacol.2019.11.530.

Müller, J.M., Kiel, D. and Voigt, K.I. (2018), "What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability", *Sustainability (Switzerland)*, Vol. 10 No. 1, p. 247.

Murmura, F. and Bravi, L. (2018), "Additive manufacturing in the wood-furniture sector: sustainability of the technology, benefits and limitations of adoption", *Journal of Manufacturing Technology Management*, Vol. 29 No. 2, pp. 350-371.

Narwane, V.S., Raut, R.D. and Gardas, B.B. (2022a), "Examining smart manufacturing challenges in the context of micro, small and medium enterprises", *International Journal of Computer Integrated Manufacturing*, Vol. 35 No. 12, pp. 1-18.

Narwane, V.S., et al. (2022b), "Examining smart manufacturing challenges in the context of micro, small and medium enterprises", *International Journal of Computer Integrated Manufacturing*, Vol. 35 No. 12, pp. 1395-1412, doi: 10.1080/0951192X.2022.2078508.

Nasrollahi, M. and Ramezani, J. (2020), "A model to evaluate the organizational readiness for big data adoption", *International Journal of Computers, Communications and Control*, Vol. 15 No. 3, pp. 1-11.

Núñez-Merino, M., Maqueira-Marín, J.M., Moyano-Fuentes, J. and Martínez-Jurado, P.J. (2020), "Information and digital technologies of industry 4.0 and lean supply chain management: a systematic literature review", *International Journal of Production Research*, Vol. 58 No. 16, pp. 5034-5061.

Obiso, J-J A., et al. (2019), "Management of Industry 4. 0 – reviewing intrinsic and extrinsic adoption drivers and barriers", *International Journal of Technology Management*, Vol. 81 Nos 3/4, pp. 210-257.

Orzes, G., Rauch, E., Bednar, S. and Poklemba, R. (2018), "Industry 4.0 implementation barriers in small and medium sized enterprises: a focus group study", 2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), pp. 1348-1352.

Osterrieder, P., Budde, L. and Friedli, T. (2020), "The smart factory as a key construct of Industry 4.0: a systematic literature review", *International Journal of Production Economics*, Vol. 221, p. 1, doi: 10.1016/j.ijpe.2019.08.011.

Ozkan-Ozen, Y.D., Kazancoglu, Y. and Kumar Mangla, S. (2020), "Synchronized barriers for circular supply chains in industry 3.5/Industry 4.0 transition for sustainable resource management", *Resources, Conservation and Recycling*, Vol. 161, p. 104986, doi: 10.1016/j.resconrec.2020.104986.

Pacheco, D. A. D J., *et al.* (2018), "Eco-innovation determinants in manufacturing SMEs from emerging markets: systematic literature review and challenges", *Journal of Engineering and Technology Management - JET-M*, Vol. 48, pp. 44-63, doi: 10.1016/j.jengtecman.2018.04.002.

Papakostas, N., James, O. and Byrne, G. (2017), "Internet of things technologies in manufacturing: Application areas, challenges and outlook", *International Conference on Information Society, i-Society 2016*, pp. 126-131.

Parente, M., Figueira, G., Amorim, P. and Marques, A. (2020), "Production scheduling in the context of Industry 4.0: review and trends", *International Journal of Production Research*, Vol. 58 No. 17, pp. 5401-5431.

Park, S. (2016), "Development of innovative strategies for the Korean manufacturing industry by use of the connected smart factory (CSF)", *Procedia Computer Science*, Vol. 91 No. Itqm, pp. 744-750, doi: http://dx.doi.org/10.1016/j.procs.2016.07.067.

Pasi, B.N. (2023), "Strategies for risk management in adopting industry 4. 0 concept in manufacturing industries", *Journal of Science and Technology Policy Management*, Vol. 14 No. 3, pp. 563-591.

Pirvu, B.C. and Zamfirescu, C.B. (2017), "Smart factory in the context of 4th industrial revolution: challenges and opportunities for Romania", *IOP Conference Series: Materials Science and Engineering*, Vol. 227 No. 1, p. 12094.

Postranecky, M. and Svitek, M. (2017), "Smart city near to 4.0 - an adoption of industry 4.0 conceptual model", 2017 Smart Cities Symposium Prague, SCSP 2017 - IEEE Proceedings, pp. 15-19.

Pradhan, A. and Agwa-Ejon, J. (2018), "Opportunities and challenges of embracing smart factory in South Africa", *PICMET 2018 – Portland International Conference on Management of Engineering and Technology: Managing Technological Entrepreneurship: The Engine for Economic Growth, Proceedings*, pp. 1-8.

Qarabsh, N.A., Sabry, S.S. and Qarabash, H.A. (2020), "Smart grid in the context of industry 4.0: an overview of communications technologies and challenges", *Indonesian Journal of Electrical Engineering and Computer Science*, Vol. 18 No. 2, pp. 656-665.

Raj, A., et al. (2019), "Barriers to the adoption of Industry 4.0 technologies in the manufacturing sector: an inter-country comparative perspective", *International Journal of Production Economics*, Vol. 224, p. 107546.

Raj, A., Dwivedi, G., Sharma, A., de Sousa Jabbour, A.B.L. and Rajak, S. (2020), "Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: an inter-country comparative perspective", *International Journal of Production Economics*, Vol. 224, p. 107546.

Rajput, S. and Singh, S.P. (2019), "Industry 4.0 – challenges to implement circular economy", Benchmarking.

Rauch, E., Dallasega, P. and Unterhofer, M. (2019), "Requirements and barriers for introducing smart manufacturing in small and medium-sized enterprises", *IEEE Engineering Management Review*, Vol. 47 No. 3, pp. 87-94.

Raza, S., Faheem, M. and Guenes, M. (2019), "Industrial wireless sensor and actuator networks in industry 4.0: exploring requirements, protocols, and challenges—a MAC survey", *International Journal of Communication Systems*, Vol. 32 No. 15, pp. 1-32.

Rocha, C.F., Quandt, C.O., Deschamps, F. and Philbin, S. (2022), "R&D collaboration strategies for industry 4.0 implementation: a case study in Brazil", *Journal of Engineering and Technology Management - JET-M*, Vol. 63, p. 101675, doi: 10.1016/j.jengtecman.2022.101675.

Rymarczyk, J. (2020), "Technologies, opportunities and challenges of the industrial revolution 4.0: theoretical considerations", *Entrepreneurial Business and Economics Review*, Vol. 8 No. 1, pp. 185-198.

Sadeghi, A.R., Wachsmann, C. and Waidner, M. (2015), "Security and privacy challenges in industrial internet of things", 2015 52nd ACM/EDAC/IEEE Design Automation Conference (DAC), pp. 1-6.

Saleem, J., et al (2018), "IoT standardisation-challenges, perspectives and solution", *ACM International Conference Proceeding Series*.

Satyro, W.C., et al (2019), "Implementation of Industry 4.0 in Germany, Brazil and Portugal: barriers and benefits", IFIP International Conference on Advances in Production Management Systems, Springer, *Cham*.

Savage, T., Grant, T.W., Nix, D., Blair, G.T., Nix Savage, T.W., Whitehead, C.J. and Blair, J.D. (1991), "Strategies for assessing and managing organizational stakeholders", *Executive (19389779)*, Vol. 5 No. 2, pp. 61-75, available at: 10.5465/AME.1991.4274682%5Cnhttp://ezproxy.csu.edu.au/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=heh&AN=4274682&site=ehost-live

Schantz, C.M.H. and Von, C. (2007), "Communicating corporate social responsibility – brand management", *Electronic Journal of Business Ethics and Organization Studies*, Vol. 12 No. 2, pp. 4-11.

Schneider, P. (2018), "Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field", *Review of Managerial Science*, Vol. 12 No. 3, pp. 803-848.

Sengupta, J., Ruj, S. and Das Bit, S. (2020), "A comprehensive survey on attacks, security issues and blockchain solutions for IoT and IIoT", *Journal of Network and Computer Applications*, Vol. 149, p. 102481, doi: 10.1016/j.jnca.2019.102481.

Shamim, S., Cang, S., Yu, H. and Li, Y. (2016), "Management approaches for Industry 4.0", pp. 5309-5316.

Sharma, M. and Sehrawat, R. (2020), "Quantifying SWOT analysis for cloud adoption using FAHP-DEMATEL approach: evidence from the manufacturing sector", *Journal of Enterprise Information Management*, Vol. 33 No. 5, pp. 1111-1152.

Sharma, A.K., et al. (2021), "A study of trends and industrial prospects of industry 4.0", *Materials Today: Proceedings*, Vol. 47 No. 40, pp. 2364-69, doi: 10.1016/j.matpr.2021.04.321.

Shayganmehr, M., Kumar, A., Garza-Reyes, J.A. and Moktadir, M.A. (2021), "Industry 4.0 enablers for a cleaner production and circular economy within the context of business ethics: a study in a developing country", *Journal of Cleaner Production*, Vol. 281, p. 125280, doi: 10.1016/j.jclepro.2020.125280.

Shi, Z., et al. (2020), "Smart factory in Industry 4.0", *Systems Research and Behavioral Science*, Vol. 37 No. 4, pp. 607-617.

Singh, A. and Misra, S.C. (2021), "1198 Advances in intelligent systems and computing", Identifying Challenges in the Adoption of Industry 4.0 in the Indian Construction Industry.

Singh, S., et al. (2018), "Challenges of digital twin in high value manufacturing", *SAE Technical Papers*, Vol. 2018, pp. 1-10.

Sirgy, M.J. (2002), "Measuring corporate performance by building on the stakeholders model of business ethics", *Journal of Business Ethics*, Vol. 35 No. 3, pp. 143-162.

Sjödin, D.R., Parida, V., Leksell, M. and Petrovic, A. (2018), "Smart factory implementation and process innovation: a preliminary maturity model for leveraging digitalization in manufacturing moving to smart factories presents specific challenges that can be addressed through a structured approach focused on people, P", *Research Technology Management*, Vol. 61 No. 5, pp. 22-31, doi: 10.1080/08956308.2018.1471277.

Sony, M. and Naik, S. (2019), "Key ingredients for evaluating industry 4.0 readiness for organizations: a literature review", *Benchmarking*, Vol. 27 No. 7, pp. 2213-2232.

Sony, M. and Naik, S. (2020), "Critical factors for the successful implementation of industry 4.0: a review and future research direction", *Production Planning and Control*, Vol. 31 No. 10, pp. 799-815.

Statsenko, L., Samaraweera, A., Bakhshi, J. and Chileshe, N. (2022), "Construction 4.0 technologies and applications: a systematic literature review of trends and potential areas for development", *Construction Innovation*, Vol. 23 No. 5, pp. 961-993.

Stentoft, J., Adsbøll Wickstrøm, K., Philipsen, K. and Haug, A. (2020), "Drivers and barriers for industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers", *Production Planning and Control*, Vol. 32 No. 10, pp. 1-18, doi: 10.1080/09537287.2020.1768318.

Suciu, G. and Hussain, I. (2019), "Smart service systems: security and privacy challenges in internet of things", *Proceedings of the 11th International Conference on Electronics, Computers and Artificial Intelligence, ECAI 2019, June*.

Sufian, A.T., et al (2019), "A roadmap towards the smart factory", *Proceedings – International Conference on Developments in eSystems Engineering, DeSE*, October-20, pp. 978-983.

Sulistiyowati, W. and Jakaria, R.B. (2018), "Assessment of technology content level with integrated technometrics and analytical hierarchy process (AHP) methods in small and medium enterprises", *IOP Conference Series: Materials Science and Engineering*, Vol. 434 No. 1, p. 12246.

Surati, S., Patel, S. and Surati, K. (2021), "Background and research challenges for FC for healthcare 4.0", *Fog Computing for Healthcare 4.0 Environments*, Springer, Cham, pp. 37-53.

Szász, L., Demeter, K., Rácz, B.G. and Losonci, D. (2020), "Industry 4.0: a review and analysis of contingency and performance effects", *Journal of Manufacturing Technology Management*, Vol. 32 No. 3, pp. 667-694.

Taghian, M., D'Souza, C. and Polonsky, M.J. (2015), "A stakeholder approach to corporate social responsibility, reputation and business performance", *Social Responsibility Journal*, Vol. 11 No. 2, pp. 340-363.

Tay, S.I., Alipal, J. and Lee, T.C. (2021), "Industry 4.0: current practice and challenges in Malaysian manufacturing firms", *Technology in Society*, Vol. 67, p. 101749.

Teck, T.S., Subramaniam, H. and Sorooshian, S. (2019), "Exploring challenges of the fourth industrial revolution", *International Journal of Innovative Technology and Exploring Engineering*, Vol. 8 No. 9, pp. 27-30.

Teng, S.Y., et al. (2021), "Recent advances on industrial data-driven energy savings: digital twins and infrastructures", *Renewable and Sustainable Energy Reviews*, Vol. 135, p. 110208.

Tiwari, S. (2021), "Supply chain integration and industry 4.0: a systematic literature review", *Benchmarking*, Vol. 28 No. 3, pp. 990-1030.

Tranfield, D., Denyer, D. and Smart, P. (2003), "Towards a methodology for developing evidence-informed management knowledge by means of systematic review", *British Journal of Management*, Vol. 14 No. 3, pp. 207-222.

Varga, P., et al. (2020), "5G support for industrial IOT applications – challenges, solutions, and research gaps", *Sensors*, Vol. 20 No. 3, p. 828.

Verma, A., et al (2019), *Advanced Sciences and Technologies for Security Applications Security and Privacy in Smart City Applications and Services: Opportunities and Challenges*, Springer International Publishing, doi: 10.1007/978-3-030-16837-7_1.

Vimal Jerald, A., Rabara, S.A. and Bai, D.P. (2017), "Algorithmic approach to security architecture for integrated IoT smart services environment", *Proceedings - 2nd World Congress on Computing and Communication Technologies, WCCCT 2017*, pp. 24-29.

Wankhede, V.A. and Vinodh, S. (2021a), "Analysis of barriers of cyber-physical system adoption in small and medium enterprises using interpretive ranking process", *International Journal of Quality and Reliability Management*, Vol. 39 No. 10, pp. 2323-2353.

Wankhede, V.A. and Vinodh, S. (2021b), "Analysis of industry 4.0 challenges using best worst method: a case study", *Computers and Industrial Engineering*, Vol. 159, p. 107487.

Wilding, R., Wagner, B., Colicchia, C. and Strozzi, F. (2012), "Supply chain risk management: a new methodology for a systematic literature review", *Supply Chain Management: An International Journal*, Vol. 17 No. 4, pp. 403-418.

Wolf, M., Semm, A. and Erfurth, C. (2018), "863 communications in computer and information science ", *Digital Transformation in Companies – Challenges and Success Factors*, Springer International Publishing, doi: 10.1007/978-3-319-93408-2_13.

Yadav, S., Garg, D. and Luthra, S. (2020), "Analysing challenges for internet of things adoption in agriculture supply chain management", *International Journal of Industrial and Systems Engineering*, Vol. 36 No. 1, pp. 73-97.

Yang, S., M. R, A.R., Kaminski, J. and Pepin, H. (2018), "Opportunities for industry 4.0 to support remanufacturing", *Applied Sciences (Switzerland)*, Vol. 8 No. 7.

Yu, M., et al. (2020a), "A survey of security vulnerability analysis, discovery, detection, and mitigation on IoT devices", *Future Internet*, Vol. 12 No. 2, pp. 1-23.

Yu, W., et al. (2020b), "A global manufacturing big data ecosystem for fault detection in predictive maintenance", *IEEE Transactions on Industrial Informatics*, Vol. 16 No. 1, pp. 183-192.

Yue, X., et al. (2015), "Cloud-assisted industrial cyber-physical systems: an insight", *Microprocessors and Microsystems*, Vol. 39 No. 8, pp. 1262-1270, doi: 10.1016/j.micpro.2015.08.013.

Zhao, G., et al. (2019), "Blockchain technology in agri-food value chain management: a synthesis of applications, challenges and future research directions", *Computers in Industry*, Vol. 109, pp. 83-99, doi: 10.1016/j.compind.2019.04.002.

Zheng, T., Ardolino, M., Bacchetti, A. and Perona, M. (2021), "The applications of industry 4.0 technologies in manufacturing context: a systematic literature review", *International Journal of Production Research*, Vol. 59 No. 6, pp. 1922-1954, doi: 00207543.2020.1824085.

Zonta, T., et al. (2020), "Predictive maintenance in the industry 4.0: a systematic literature review", *Computers and Industrial Engineering*, Vol. 150, p. 106889.

Appendix

References	Focus
Mrugalska and Ahmed (2021)	The current state of knowledge of organizational agility in Industry 4.0 The role of Industry 4.0 technologies in organizational agility
Zheng *et al.* (2021)	The applications of Industry 4.0 enabling technologies in manufacturing business processes
Cioffi *et al.* (2020)	Identifying the scientific community interest about digital manufacturing systems
Cui *et al.* (2020)	Discovering the drivers and requirements for big data applications in smart manufacturing Identifying the vital components of big data ecosystem to a better serving of smart manufacturing
Tiwari (2021)	The existing state of understanding and knowledge, which is available on Industry 4.0 and SCI The core research directions with reference to the adoption of Industry 4.0 and SCI
Abdirad and Krishnan (2020)	Identifying the existing knowledge and trends in Industry 4.0.
Hizam-Hanafiah *et al.* (2020)	Identification of the existing Industry 4.0 readiness models (academia/industry)
Osterrieder *et al.* (2020)	Analysis of the level of development in field of smart factory researches. Cluster the diverse perspectives with regard to their thematic context
Amjad *et al.* (2020)	Identifying the available approaches in manufacturing sector that cater to either of lean, agile, resilient, green practices or the LARG paradigm Identifying the appropriate methodology for technology-based LARG implementation
Sony and Naik (2020)	Identification of the key ingredients for assessing the readiness for Industry 4.0 for organizations Interrelationships will exist between these readiness factors
Egger and Masood (2019)	Examining the present research status and challenges connected to AR
Bag *et al.* (2018)	Discovering the Industry 4.0 enablers of sustainable supply chain management Developing a model by integrating the concept of Industry 4.0 and sustainable supply chain management
Mittal *et al.* (2018)	Whether the current smart manufacturing maturity models a good fit for the specific requirements of manufacturing SMEs or not How can the current smart manufacturing maturity models are adapted to support SMEsgfttr43' specific requirements in their evolutionary path and the paradigm shift toward SM and Industry 4.0?
Kamble *et al.* (2018a)	Discovering the different research approaches used to study Industry 4.0 Assessing the status of research in the domains of Industry 4.0

Table A1. A number of related works

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