Industry 4.0 Adoption in Supply Chain Operations: A Systematic Literature Review

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Abstract. Industry 4.0 adoption in industry and business has grown extensively. Supply chain had an opportunity to adopt Industry 4.0 in improving flexibility, efficiency, and response to consumer demands. Considering Industry 4.0, adoption in supply chain operations must be realized as an opportunity and challenge for practitioners. Hence, this study conducted a systematic literature review with a qualitative and quantitative approach to formulate supply chain 4.0 dimensions and operations in assessing readiness for adopting industry 4.0. A Preferred Reporting Item for Systematic Review and Meta-analyses (PRISMA) and bibliometric analysis are performed to analyze the literature related to industry 4.0 adoption in supply chain operations. This research combined a qualitative and quantitative analysis in reviewing the literature to deliver a broader benefit of Industry 4.0 in supply chain operations. This study found 525 papers related to Industry 4.0. Moreover, only twenty papers discussed supply chain specifically. Literature analysis using quantitative and qualitative approach showed that industry 4.0 adoption in the supply chain is limited to the maturity model with digital transformation. This study proposed five comprehensive dimensions to capturing supply chain operations: technology and information technology (IT) infrastructure, supply chain integration and coordination, manufacturing operations and inventory, leadership and human resources, and sustainability. The proposed dimensions for supply chain operations are based on a conceptual analysis of literature. Further verification and empirical analysis is needed to gain deeper insights. While digital technology and transformation are the main focus of Industry 4.0 adoption in many sectors, supply chain management requires broader applications as it involves various sectors and stakeholders. To further analyze this, a readiness and maturity model needs to be developed to assess the adoption of Industry 4.0 in the supply chain, taking into consideration the proposed dimensions.

Keywords: Industry 4.0; Maturity; Readiness; Supply chain; Systematic literature review

1. Introduction

Supply chain management was first considered during the second world war to achieve an efficient operation. Ballou (2007) has defined the concept of Supply Chain Management (SCM) as coordinating stakeholder across product flow to achieve goals. Definitely, SCM organized 3 main flows, including product/material, cost, and information, with primary and secondary stakeholders (Asrol, Yani, and Taira, 2021). The supply chain goals are generally defined as two main focuses, fulfilling consumer demand and achieving maximum

profit (Chopra and Meindl, 2013). Moreover, supply chain management and operations face a huge challenge to achieve an efficient and effective process to fulfil consumer demand.

During the advancement of technology and information system, supply chain management is improved. Since the concept of Industry 4.0 was first introduced in 2013 (Kagermann, Wahlster, and Helbig, 2013), supply chain management with the advancement of technology and digital transformation must be considered in the industry (Wagire et al., 2021). As we know, Industry 4.0 is the new industrial revolution into a digital and smart factory system that provides an opportunity to adopt business intelligence and digital transformation in the business model operation (Lasi et al., 2014). (Schumacher, Erol, and Sihn, 2016) put a strong line of industry 4.0 as the integration of manufacturing systems among vertical and horizontal stakeholders through digital transformation in the entire value chain. Regarding these definitions, a supply chain as the integration of stakeholders in the industrial production system must be prepared to adopt the industry 4.0 revolutions to achieve benefits in winning competitive advantages.

The implementation of Industry 4.0 offers exciting potential for the industry's transformation. Moreover, some considerations must be realized. One of the Industry 4.0 opportunity is to build a sustainable business model that is organized by value, supply chain, customer relationship, efficiency, productivity, and financial model (Dudukalov et al., 2021; De-Man and Strandhagen, 2017). Scholars have provided the concept and practical applications of Industry 4.0, e.g., blockchain and IoT for sustainable supply chain (Esmaeilian et al., 2020; Alladi et al., 2019), digital SCM to managing risk and disruption (Ivanov and Dolgui, 2020). Further, the supply chain considerations in Industry 4.0 adoption need attention to support business transformation and sustainability (Zhang et al., 2021; Manavalan and Jayakrishna, 2019). a comprehensive literature review is required to understand the effects of Industry 4.0 on the supply chain regarding preparing to industry's supply chain to adopt the technology since practitioners lose of the initial stage to apply the concept and technology (Shao et al., 2021; Kenge et al., 2020). In this context, a readiness level assessment is required to identify the current industry's performance in achieving supply chain 4.0 adoption.

Research on the readiness and maturity level of Industry 4.0 in the supply chain has been conducted by several scholars. Monshizadeh et al. (2023) and Caiado et al. (2021) developed a fuzzy system to assess readiness, while Lassnig et al. (2021) proposed a SCOR-based readiness with a Likert-scale to evaluate Industry 4.0 adoption. Azevedo and Santiago (2019) provided a qualitative and quantitative assessment of Industry 4.0 adoption in Manufacturing. Most of the research found that it is applied in small and medium enterprises for manufacturing system assessment. The dimensions and attributes to assess the readiness were limited to manufacturing operations and avoiding the SCM perspective. Previous research has provided models with various dimensions to assess the readiness level for Industry 4.0. Schumacher, Erol, and Sihn (2016) designed nine dimensions to assess industry maturity and achieve Industry 4.0 adoptions through surveys in related industries. Rajnai and Kocsis (2018) proposed technology, culture, organization, and culture as dimensions to assess Industry 4.0 readiness level. Machado et al. (2019) evaluated the digital readiness and capability of the industry with self-check tools to investigate the industry's maturity level. Hizam-hanafiah, Soomro, and Abdullah, (2020) proposed six dimensions, including technology, people, strategy, Leadership, process, and innovation, with technology being the most important dimension to assess Industry 4.0 readiness

Various dimensions and models to assess industry 4.0 readiness. Moreover, we found a lack of applications to adopt for supply chain readiness (Lassnig et al., 2021). Most of the

dimensions adopted in the model focus on the effect of digital technology and transformation, while the other supply chain perspectives lack attention. In this case, it is required to define dimensions to assess the current readiness level. Even though some literature has provided dimensions and indicators for industry 4.0 adoption, as far as the author's knowledge, there is scarce literature to define the supply chain implementation, and it only focuses on digital technology and transformation. Therefore, this research provides a systematic literature review (SLR) with a combination of a qualitative and quantitative approach to formulate the supply chain dimensions in adopting industry 4.0 implementation. This approach is proposed to reduce the systematically biased result (Tangpong, 2011) and authors' subjective decision and lead to a valid research mapping and gaps also further research recommendations.

The objective of the research is to conduct a systematic literature review (SLR) with a quantitative and qualitative approach to formulate the supply chain 4.0 concept and readiness dimensions in adopting industry 4.0. Future research is also provided to draw potential fields to be explored to fill the gap in the future. The original contribution of the paper is to provide common dimensions applied in industry 4.0 for supply chain implementation and propose a new comprehensive dimension for supply chain 4.0 readiness.

This paper is organized as follows: in section 2, the step-by-step systematic literature review model is explored. Section 3, result and discussion, delivers a systematic literature review analysis and provide future research discussion and implementation. Finally, section 4 concludes the paper with contributions, limitations, and recommendations for further research.

2. Methods

2.1. Research stages

To contribute for industrial engineering body of knowledge, this research proposed a Systematic Literature Review (SLR) on supply chain 4.0. In this research, a methodology of Preferred Reporting Items for Systematic Review and Meta-analyses (PRISMA) by (Moher et al., 2009) is adopted to analyze the literature related to industry 4.0 adoption in the supply chain.

To deepen our analysis, we combine the PRISMA framework with VOSviewer analysis that provides a quantitative approach with bibliometric analysis to strengthen the analysis and provide further research agenda. VOSviewer analysis was found by (Van-Eck and Waltman, 2010) and has largely been applied in the literature reviewing process. The combination of PRISMA and VOSviewer analysis provides a complete further research gap. The research framework is depicted in Figure 1.
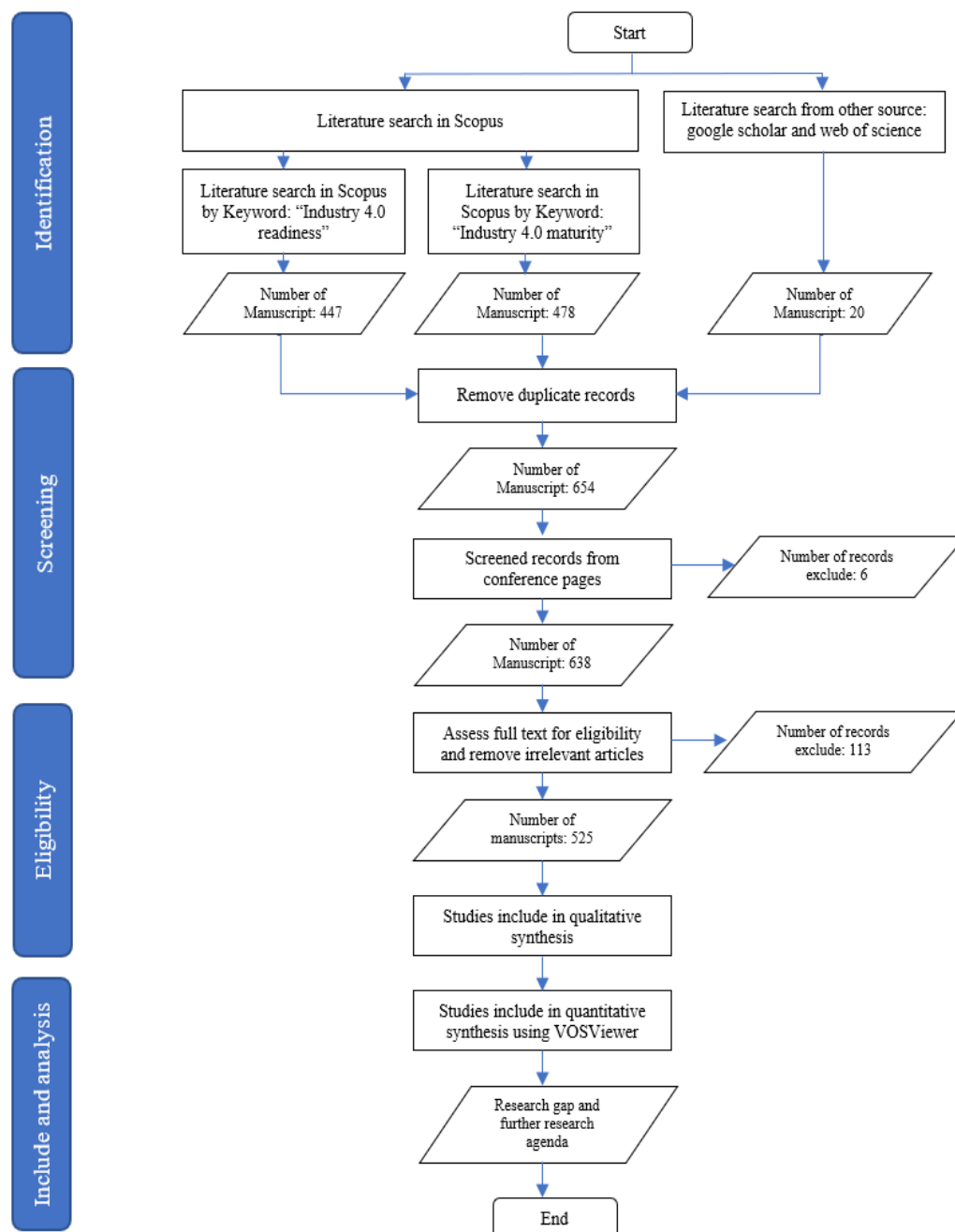
Figure 1 Research framework

2.2. Data sources

Regarding the research framework, this research collected literature from the Scopus database and other resources. The other resources involve google scholar and Web of Science which are related to the topic. In the case of taking literature from the Scopus database, three keywords were applied, "Industry 4.0 AND readiness" OR "Industry 4.0 maturity". Readiness and maturity are two representative words that may extract much information in linking the gap and developing the supply chain 4.0 model in the literature.

These keywords were applied to collect as much as possible literature related to the topic. We restricted the year of publication after 2013 since Industry 4.0 was first introduced in 2013 by German scientists and engineers (Kagermann, Wahlster, and Helbig, 2013). We collected the data in February 2022. Therefore, the number of publications in

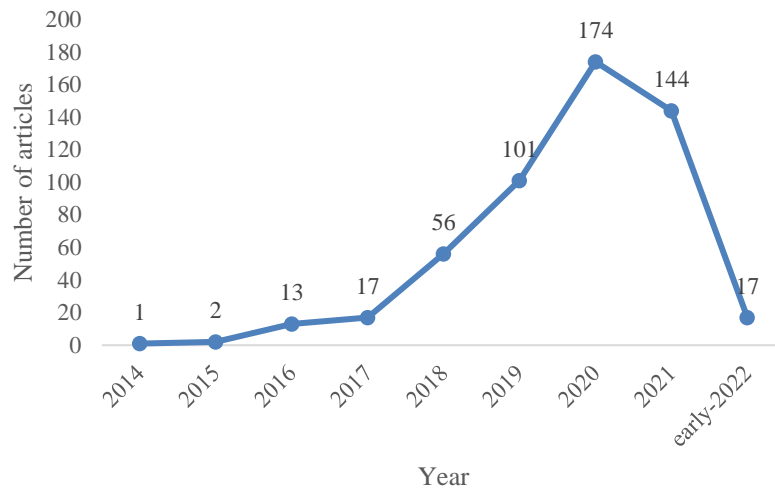2022 is limited. The year of publication distributions from the Scopus database is depicted in Figure 2.

Figure 2 Year of publication distribution of related literature

2.3. Data analysis and performed further research agenda

In the first stage, literature is collected from Scopus and another database. For the Scopus database, we apply two keywords: 'industry 4.0 readiness' and 'industry 4.0 maturity'. Terms of maturity and readiness are found as the most keywords to describe any industry 4.0 adoption in Industry (Frederico *et al.,* 2020). After moving some duplicate literature, we found 654 kinds of literature. We apply the screening and eligibility process by removing articles from the conference homepage and excluding 113 irrelevant articles.

We have 525 kinds of literature for further statistical descriptive analysis to see the article types, sources and publishers, and year of publication distribution. A quantitative with bibliometric analysis is also applied using VOSviewer tools to find the research gap and propose the supply chain 4.0 adoption in the industry. A tabular list of relevant literature is provided to find supply chain dimensions to apply in the industry. Finally, we synthesize the further research agenda in implementing supply chain 4.0 in the industry. The further research agenda is formulated based on the keywords networks and literature relations described by Vosviewer, qualitative analysis of the previous research in industry 4.0 and supply chain adoption, and proposed dimensions to assess supply chain 4.0 readiness. Further research agenda is focused on how to apply the dimensions and research gap found in qualitative and quantitative analysis of previous research.

3.   Results and Discussion

3.1.   Statistical descriptive of the relevant literature

Research related to Industry 4.0 has grown extensively during the last decade. After collecting articles and identification, screening, and eligibility with respect to PRISMA methodology, 525 articles with the terms industry 4.0 are analyzed. Figure 3 shows the publisher with the highest number of published articles (more than ten articles) with the terms Industry 4.0 from 2013 to February 2022 in the Scopus database. Further, most of the articles are published in journals and conference proceedings, as shown in Figure 4.
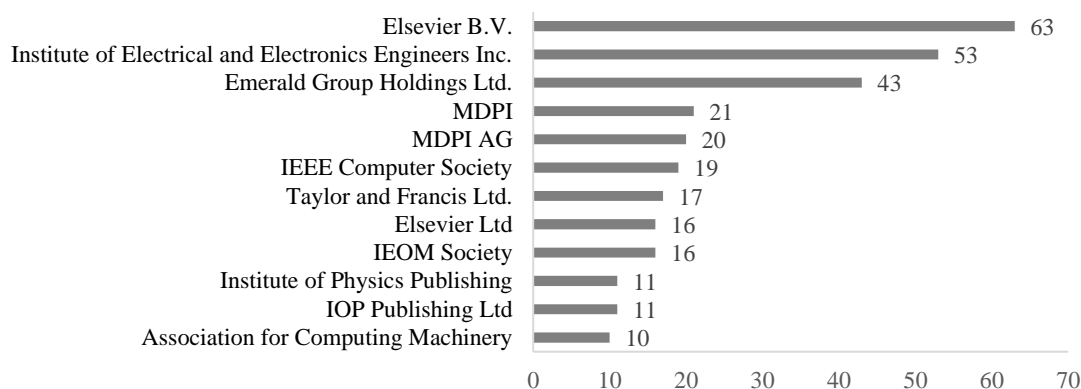
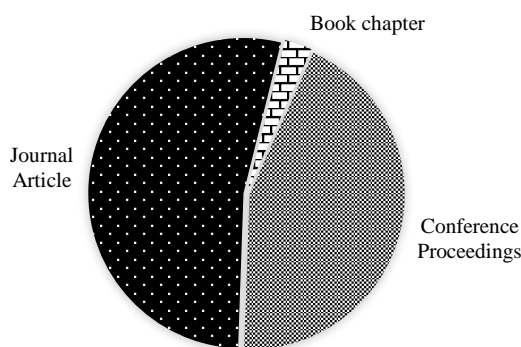**Figure 3** Publisher with ten papers and more with topic industry 4.0

Figure 4 Reviewed articles type distribution

Previous research has extensively described that industry 4.0 adoption is an opportunity to improve industrial operations and efficiency. Moreover, most of the applications of Industry 4.0 operations are only focused on the operations at the firms. As stated by (Frederico *et al.,* 2020) that there is a limited application of Industry 4.0 in the supply chain. Considering the definition of the supply chain by (Chopra and Meindl, 2013) and (Ballou, 2007), supply chain management organizes many activities, internal and external, of the firms which aim to improve efficiency and effectiveness, produce a high-quality product and the lowest cost, and maximize profit, it is confirmed that this subject is noteworthy to involve in industry 4.0 adoption. According to Tripathi and Gupta (2021) and Dallasega, Rauch, and Linder (2018), considering the supply chain in Industry 4.0 adoption can enhance business activities and transform the entire process from manufacturing to distribution and sales.

A bibliometric analysis using VOSviewer was applied to analyze the relevant literature quantitatively. Using a keyword network analysis, we found that there are five clusters of keywords linked to each other to Industry 4.0, as shown in Figure 5. A full counting method is applied in this analysis to see the full links and contribution of the authors to the keywords and article (Perianes-Rodriguez, Waltman, and Van-Eck, 2016). We found that the relations between Industry 4.0 and supply chain terms are scarce. It is also confirmed that the application of Industry 4.0 in the supply chain is limited in the current literature and has not been largely discussed. Our result also confirmed that the Industry 4.0 adoption in supply chain operation was mostly published after 2020, as described in Figure 6.
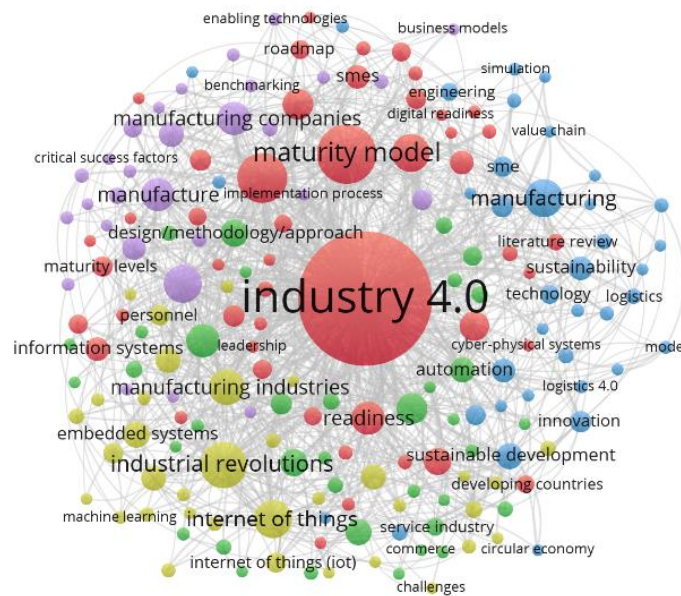
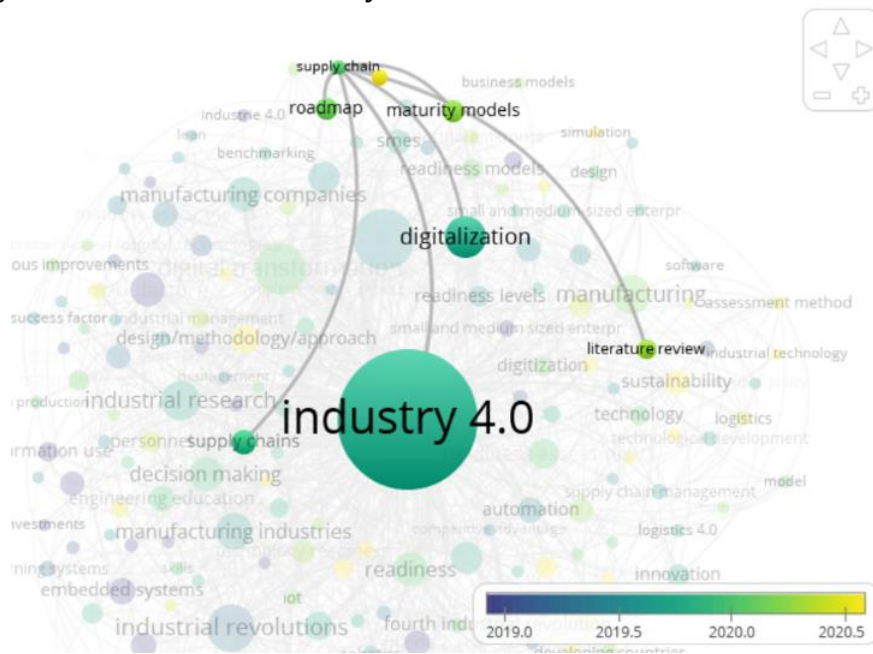**Figure 5** Keyword networks of Industry 4.0 in literature

Figure 6 The relations of Industry 4.0 and supply chain in literature

3.2. Reporting findings of SLR on supply chain 4.0

The terms of Industry 4.0 has been largely discussed in developing a system and business process. Industry 4.0 aims to connect the system between a real and virtual factory with the cyber-physical system and the Internet of Things to achieve efficient production. In terms of the objective of the concept, research related to Industry 4.0 has been largely found in the literature. Most of the research discusses the conceptual model, maturity, and readiness level of the business in adopting Industry 4.0.

The Industry 4.0 also influences to the upstream and downstream of the value chains (Asdecker and Felch, 2018), offering a quick response to consumer demand (Manavalan and Jayakrishna, 2019) and improving the supply chain flexibility and transportation (Tjahjono *et al.,* 2017). In the context of carrying out the benefit of Industry 4.0, therefore the supply chain operations must be considered in further Industry 4.0 applications.

Moreover, the previous analysis clearly found that there is a limited discussion about the supply chain in industry 4.0 adoption. Literature extracted from the database shows that only a few papers contribute to supply chain 4.0, as shown in Table 1.

Table 1 Literature contribution to supply chain 4.0

No	Author	Main contribution	Type
1	(Tjahjono et al., 2017)	Industry 4.0 increased flexibility, quality standards, efficiency, and productivity. It was found that not all parts of Industry 4.0 affect supply chain operations.	Conference proceeding
2	(Asdecker and Felch, 2018)	Formulate maturity model for delivery process in the supply chain using supply chain operation reference model. Maturity model is designed by the company's production strategy	Journal Article
3	(Dallasega, Rauch, and Linder, 2018)	A review paper found that Industry 4.0 improve productivity and enhances product development to distribution processes of the supply chain	Journal Article
4	(Methavitakul and Santiteerakul, 2018)	Developing dimensions and sub-dimensions of Industry 4.0 performance assessment	Conference Proceedings
5	(Krykavskyy, Pokhylchenko, and Hayvanovych, 2019)	Identifying main drivers in supply chain 4.0 and highlighting digital technology as the main driver.	Journal Article
6	(Machado et al., 2019)	Provided a case study of seven companies to assess the current industry 4.0 maturity level	Conference proceeding
7	(Frederico et al., 2020)	A review paper to formulate a framework in the supply chain 4.0 maturity model with a limited number of papers.	Journal Article
8	(Van Hoek et al., 2020)	Find the opportunity to adopt industry 4.0, human interaction in technology adoption, and sustainability combination in supply chain 4.0.	Journal Article
9	(Hizam-hanafiah, Soomro, and Abdullah, 2020)	A review paper that found technology as the most important dimension in supply chain 4.0 adoption	Journal article
10	(Hajoary, 2020)	Formulate ten dimensions for Industry 4.0 readiness and maturity assessment	Journal article
11	(Agca et al., 2020)	Formulate industry 4.0 and supply chain 4.0 dimensions for maturity assessment	Book
12	(Hellweg et al., 2021)	A review paper that focuses on the digital technology dimension of supply chain 4.0 adoption	Journal Article
13	(Tripathi and Gupta, 2021)	Interconnectivity is the core of Industry 4.0 that enables it to be adopted in the supply chain	Journal Article
14	(Dudukalov et al., 2021)	A statistical research approach to provide evidence of the effect of digital transformation on the supply chain	Conference Proceedings
15	(Lassnig et al., 2021)	Define the difference between digital transformation in the supply chain for a small and large company	Journal article
16	(Shayganmehr et al., 2021)	Design an assessment system of trust and coordination for supply chain readiness in industry 4.0 adoption	Journal article
17	(Khan et al., 2021)	Using a knowledge-based view approach to assess supply chain digitalization readiness level.	Journal article
18	(Reyes, Mula, and Díaz-Madroñero, 2021)	Linking the lean supply chain with Industry 4.0 in supply chain 4.0 implementation	Journal article
19	(Wagire et al., 2021)	Developing a maturity model to assess Industry 4.0	Journal article
20	(Bentaher and Rajaa, 2022)	Proposed an intelligent supply chain framework based on a literature review	Journal article

Previous scholars defend the one point that Industry 4.0 contributes to supply chain operations, despite its lack of definition and applications. (Tjahjono et al., 2017) And (Dallasega, Rauch, and Linder, 2018) agreed that Industry 4.0 adoption might improve supply chain flexibility, productivity, product quality, and distribution. Supply chain

operations have advantages to win competitive advantages and fulfilling consumer expectations. Besides that, another research also found that the implementation of Industry 4.0 in a supply chain may improve the decision-making process and human-machine interaction system (Van Hoek *et al.,* 2020; Manavalan and Jayakrishna, 2019).

Most of the literature provides the industry 4.0 maturity and readiness model assessment with various dimensions and models. After the extraction process, Table 1 provides a supply chain 4.0 readiness and maturity assessment with various dimensions. From the listed literature, this paper draws a conclusion, as far as the author's knowledge, that previous research was only focused on digital technology and transformation in assessing supply chain 4.0 adoption. Most scholars (see: (Dudukalov *et al.,* 2021; Hellweg *et al.,* 2021; Khan *et al.,* 2021; Lassnig *et al.,* 2021; Hizam-hanafiah, Soomro, and Abdullah, 2020; Gupta *et al.,* 2020; Krykavskyy, Pokhylchenko, and Hayvanovych, 2019)) stated that digital technology and transformation as the most important dimensions in supply chain 4.0 adoption. Moreover, (Tjahjono *et al.,* 2017) delivered that the industry 4.0 adoption for the supply chain is possible to support consumer demand fulfilment and transportation. Focusing on industry 4.0 adoption in the supply chain for digital technology and transformation is not a wise decision since the supply chain is not only about the facility but also about the production process, delivery, coordination, stakeholder, and distribution as defined in (Chopra and Meindl, 2013; Ballou, 2007).

3.3. Formulating supply chain 4.0 dimensions

In assessing supply chain 4.0 readiness considers complex factors, indicators must be defined in a specific manner. These indicators are compromised into groups called dimensions (Rajnai and Kocsis, 2018). To formulate supply chain 4.0 dimensions, literature that discussed industry 4.0 related to supply chain implementation is analyzed. Before, a list of literature that discusses supply chain 4.0 adoption has been delivered. After that, literature that focuses on the supply chain 4.0 maturity and readiness model is extracted. The literature that applied to supply chain 4.0 assessment provides a various number of dimensions as depicted in Figure 4.
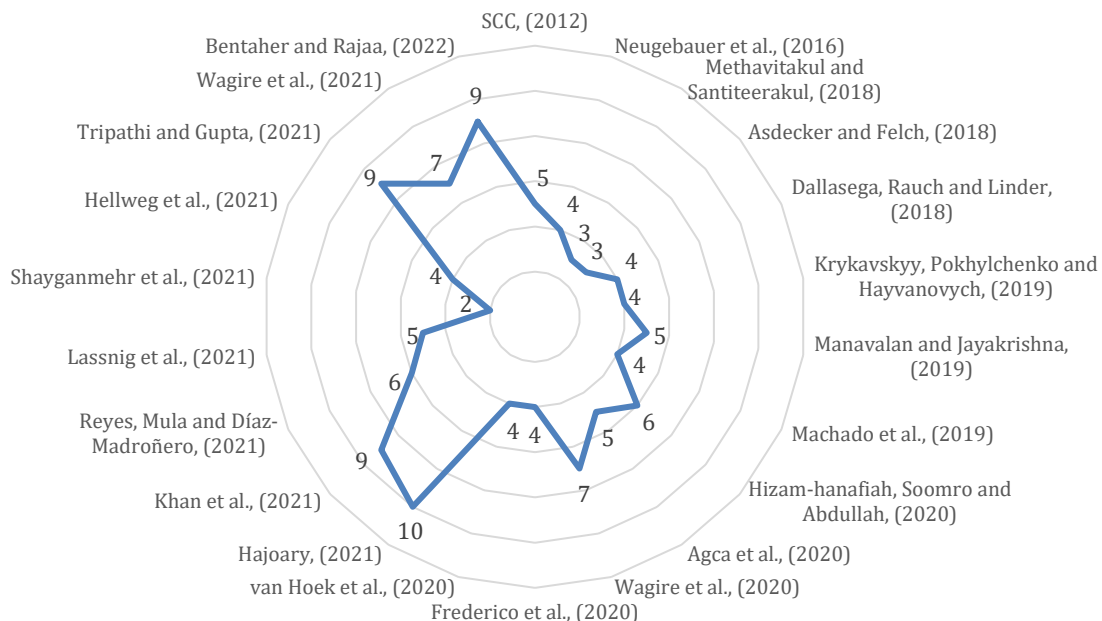

Figure 7 Number of dimensions considered for supply chain 4.0 in literature

The number of dimensions in each research is diverse. Most papers published before 2020 served less than 5 dimensions to assess industry 4.0 and supply chain 4.0 readiness,

while articles published after 2020 provide 5-10 dimensions, except (Shayganmehr *et al.,* 2021) that focus on supply chain coordination. We found that most research that proposed industry 4.0 adoption in supply chain adoption has delivered dimensions. Moreover, it is limited to digital technology and transformation.

The supply chain dimensions in industry 4.0 adoption readiness that is mentioned in the literature is limited. Since most of the literature focus on digital technology and transformation, we proposed new dimensions to assess supply chain 4.0 readiness to capture supply chain operation completely. Five dimensions are proposed, Technology and IT infrastructure, Supply chain integration and coordination, Manufacturing operations and inventory, Leadership, and human resource and Sustainability.

Before, Hizam-hanafiah, Soomro, and Abdullah, (2020) also clustered dimensions for industry 4.0 readiness assessment. This research proposed dimensions for supply chain 4.0 readiness assessment since it was limited to find in the literature. Table 2 shows the proposed dimensions to assess supply chain 4.0 readiness. The first column provides supply chain 4.0 dimensions from previous literature. We cluster dimensions based on meaning and usage. Column 2 shows the number of dimensions that has meaning and usage extracted from the literature. Proposed dimensions are provided in column 3 based and general meaning and its relation to the previous research dimensions.

Table 2 Proposed supply chain 4.0 dimensions

Dimensions from existing literature	Number of dimensions	Proposed dimensions
Information and communication technology (ICT) policies, IT network Infrastructure, Technological structure, Infrastructure, Technology, Autonomous system, Big data handling, Smart manufacturing, industry 4.0 base technology, Digitalization of the vertical and horizontal value chain, Innovative digital technology, Technology and digitalization, Digital awareness, Cybersecurity, Technology, Learning machine, End to end IT enabled planning, Digitalization of product equipment, Technology levers, Technological advancements, Information technology.	21	Technology and IT infrastructure
Collaboration, Supply chain integration, Supply chain visibility, Connectivity, Coordination, Digitalization of vertical and horizontal value chain, Partnership, Flexibility, Lead times, Supply chain flow, Customers, Services, Supplier enabled, Supply chain performance, Agility, Supply chain planning.	16	Supply chain integration and coordination
Product and service-oriented, Real-time monitoring and control, Value chain and processes, Business, Process and method, Process performance requirements, Efficiency, Industrial improvement, Cost, Asset, Lean manufacturing practice, Use of smart technologies in logistics, Use of smart technologies in production, Manufacturing, and Operations, Product, Business Model, Inventory control using real-time, Inventory control, Use of smart technologies in the warehouse, and Digitalization of product equipment.	20	Manufacturing operations and inventory
Human resources, Organizational, Managerial, and capability supporter, Skilled human resources, Startup culture, Leadership, People, and Innovation. Worker IT skills, People and culture, Organizational strategy, Talent for the future, Management strategy, Enterprise transformation management, Strategic outcomes, Responsibility, Management strategy, Training Policy, Strategy, and Organization, and Innovation incubating.	20	Leadership and human resources
The regulatory environment, Human resources, People and culture, Regulations, Swift trust, Waste management and quality, Sustainable development, Innovation capability, People and culture, Sustainability, and Government support.	11	Sustainability

As also stated in the previous research, technology, and IT infrastructure are the most dimensions considered in supply chain 4.0. Using technology and IT infrastructure in supply chain operations may improve stakeholders' connectivity and information sharing to enhance supply chain effectiveness (Preindl, Nikolopoulos, and Litsiou, 2020). There are twenty-one dimensions from previous research related to technology and IT infrastructure. It is also confirmed that applying Industry 4.0 to the supply chain should pay attention to technological advancement and infrastructure. Further, technology is not the only dimension to consider in supply chain 4.0 adoption.

This research found that supply chain integration and coordination and Manufacturing operations and inventory are also needed to consider in supply chain 4.0 since its operations involve many stakeholders. Integrations and coordination using Industry 4.0 technology are still distant, even if it may improve supply chain performance and competitive advantages (Preindl, Nikolopoulos, and Litsiou, 2020; Asrol *et al.,* 2018). In this context, supply chain integration and coordination are clustered based on any dimensions from previous research that are related to the dimensions. It is found that sixteen dimensions from previous research clustered into supply chain integration and coordination which confirmed that this dimension has not been considered, even though the context is supply chain operations.

For the manufacturing operations and inventory, it is found that twenty dimensions from previous research related to this proposed dimension. In other research, (Sanders, Elangeswaran, and Wulfsberg, 2016) also consider Industry 4.0 in Manufacturing operations with a lean approach, which illustrates this scope is necessary to be included in the supply chain 4.0 modelling. We proposed Manufacturing operations and inventory due to fulfilling industry 4.0 requirements in the focal company in the supply chain. Manufacturing operations and inventory involve warehouse operations, productions process and models, efficiency, business model, and smart technology practice in the supply chain, which mostly deal with industry 4.0 adoption.

Leadership and human resource dimension are proposed to deal with resources capability in organization, innovation, and technology (Chumnumporn *et al.,* 2022; Naruetharadhol *et al.,* 2022). We found twenty dimensions from previous research related to this proposed dimension. Human interaction and organization with good Leadership may assist industry 4.0 adoption in supply chain operations.

Table 3 Previous research related to proposed dimensions

No	Author	Technology and IT Infrastructure	Supply chain integration and coordination	Manufacturing operation and inventory	Leadership and human resources	Sustainability
1	(Neugebauer *et al.,* 2016)	X		X	X	
2	(Methavitakul and Santiteerakul, 2018)	X	X	X		
3	(Manavalan and Jayakrishna, 2019)	X	X			X
4	(Dallasega, Rauch, and Linder, 2018)	X	X		X	
5	(Asdecker and Felch, 2018)		X	X		
6	(Krykavskyy, Pokhylchenko, and Hayvanovych, 2019)	X	X	X		
7	(Machado *et al.,* 2019)	X	X	X		
8	(Frederico *et al.,* 2020)	X		X	X	
9	(Agca *et al.,* 2020)		X	X		
10	(Van Hoek *et al.,* 2020)	X	X		X	X
11	(Hizam-hanafiah, Soomro, and Abdullah, 2020)	X	X	X	X	
12	(Hajoary, 2020)	X		X	X	
13	(Khan *et al.,* 2021)	X	X	X		
14	(Hellweg *et al.,* 2021)	X		X	X	
15	(Tripathi and Gupta, 2021)	X			X	X
16	(Reyes, Mula, and Díaz-Madroñero, 2021)	X	X	X		
17	(Lassnig *et al.,* 2021)		X	X		
18	(Shayganmehr *et al.,* 2021)		X			
19	(Wagire *et al.,* 2021)	X		X	X	
20	(Bentaher and Rajaa, 2022)	X	X	X		X
	Total	17	14	15	9	5

Finally, this research proposed sustainability dimensions to assess the readiness of supply chain 4.0 adoption in the industry. This dimension is to fulfil gaps in industry 4.0 adoption study that received limited attention in economic, social, and institutional aspects (Fogaca, Grijalvo, and Neto, 2022; Oesterreich, Schuir, and Teuteberg, 2020). The sustainability dimension is clustered based on eleven dimensions from previous research which confirmed that this dimension had not been mentioned before. However, considering sustainability in Industry 4.0 and supply chain operation has been suggested by previous research (Berawi *et al.,* 2020; Manavalan and Jayakrishna, 2019; De-Man and Strandhagen, 2017). Therefore, sustainability dimension is required in the supply chain 4.0 adoption and readiness.

An overview of previous research related to the proposed dimensions is shown in Table 3. It was found that Technology and IT infrastructure are the most applied dimensions in the literature, in line with our previous analysis. Supply chain integration and coordination and manufacturing operation and inventory are also found in 15 and 14 papers related to this dimension, respectively. Leadership and human resource found nine papers discuss this dimension, while sustainability is the most limited dimension considered in previous research.

3.4. Further research agenda

Existing literature drawing Industry 4.0 maturity and readiness has delivered meaningful concepts and applications. Moreover, Industry 4.0 adoption is not limited to business and operations in a focal company. It needs to expand along the supply chain flow to improve the value chain and met consumer expectations. A systematic literature review has revealed that the Industry 4.0 topic is a fascinating topic. 525 kinds of literature were extracted.

However, due to a requirement to adopt Industry 4.0 in the supply chain, a bibliometric analysis also found interesting facts. Supply chain keywords that are related to Industry 4.0 is limited in the last 3 years and need to fill the gap since its offer a great benefit to efficiency and effectiveness. From the enormous number of literature related to Industry 4.0 topics, only 20 papers discussed supply chain 4.0 adoption. These papers cover a range of topics related to Industry 4.0 adoption in the supply chain, including maturity and readiness assessment, case studies on supply chain readiness, digital transformation in the supply chain, and the importance of Supply Chain 4.0 for improving operational efficiency.

Previous research has formulated various dimensions related to Industry 4.0 and supply chain 4.0 readiness. Moreover, most of the dimensions promote the importance of digital technology and transformation adoption. Stakeholders push to apply Industry 4.0 in the supply chain. However, the implementation only focuses on digital transformation and tends to remove other important supply chain sectors (Wagire *et al.,* 2021; Krykavskyy, Pokhylchenko, and Hayvanovych, 2019). In fact, in adopting Industry 4.0 is not only focused on technology advancement and transformation but also it is potentially to minimize production waste, energy use optimization, and green-house gas impact (Kiel *et al.,* 2017). To adopt the focus and benefit of Industry 4.0 in the supply chain, this paper has drawn dimensions of the previous research and proposed five comprehensive dimensions: Technology and IT infrastructure, Supply chain integration and coordination, Manufacturing operations and inventory, Leadership and human resources, and Sustainability.

The proposed dimensions need to decompose to detail indicators and design the assessment model of readiness and maturity. For further research agenda, a self-assessment approach is recommended for the practitioner to monitor current supply chain performance using the proposed dimensions. In future research, each dimension must be

decomposed into indicators that are adapted from the individual dimensions from the previous research. In designing an assessment model, dimensions and indicators must be defined completely. Dimensions describe supply chain 4.0 in many perspectives while indicators explain the performance of the dimensions (Juwana, Muttil, and Perera, 2012). As found in the listed literature, previous research has provided Industry 4.0 readiness.

This paper comes with a specific perspective to design the supply chain 4.0 readiness considering a multi-dimensional approach. Moreover, for further research agenda in designing a supply chain 4.0 readiness model must pay attention to the weakness of the previous model: focus on a qualitative approach with descriptive elements (Rajnai and Kocsis, 2018), Likert-scale assessment with primary data collection model (Schumacher, Erol, and Sihn, 2016) and a short industrial survey (Machado *et al.*, 2019).

A mixed-methodology approach in designing the supply chain 4.0 readiness model is required, as proposed in quantitative analysis using Vosviewer as aforementioned Due to the uncertainty factors in the field with the need for a valid assessment model, a systematic approach is necessary. A combination of the mixed method using qualitative and quantitative data analysis for supply chain readiness assessment may reduce systematically biased results and lead to a valid model (Caiado *et al.,* 2021; Tangpong, 2011). In this context, this paper recommends designing a supply chain 4.0 readiness model with a qualitative and quantitative indicator is decomposed by the proposed dimensions: Technology and Information Technology (IT) infrastructure, Supply chain integration and coordination, Manufacturing operations and inventory, Leadership and human resources, and Sustainability. A quantitative and qualitative approach in the assessment model followed by a related multi-methodology hard and soft system approach may produce a robust model to assess supply chain 4.0 readiness and monitoring. This approach was also recommended by (Yani *et al.,* 2022) for supply chain sustainability assessment (Caiado *et al.,* 2021; Schumacher, Erol, and Sihn, 2016) for industry 4.0 readiness that obtained qualitative and quantitative data with a valid result.

4.   Conclusions

A literature review with a qualitative and quantitative approach for the Industry 4.0 maturity and readiness has been delivered. Supply chain 4.0 met a lack of discussion and implementation during the industry 4.0 adoption. This paper found 525 papers discuss industry 4.0 readiness and maturity and are limited to the implementation of supply chain 4.0. Papers that discussed supply chain 4.0 focused on the importance of digital technology and transformation in the adoption, while supply chain needs another perspective. A quantitative and qualitative approach in reviewing process using PRISMA and VOSviewer approach, this paper has proposed a comprehensive dimension to assess supply chain 4.0 readiness. The proposed dimensions are Technology and IT infrastructure, Supply chain integration and coordination, Manufacturing operations and inventory, Leadership and human resources, and sustainability formulated by the dimensions mentioned in the previous research. For further research, it needs to design a completed supply chain 4.0 readiness model assessment with the proposed dimensions which needs to decompose into a qualitative and quantitative dimension. A multi-methodology with a hard and soft system approach is required to design the model since it found a valid result. However, limitations regarding this study must be considered. First, the source of the literature review is a single database with some paper addition. Including another database may propose a unique result. Second, the proposed dimensions are formulated based on the previous dimensions in the literature. To decide a dimension into a cluster dimension is a subjective decision of the author. Verification by a prominent expert is needed to accomplish this part.

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