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Defining SMEs' 4.0 Readiness Indicators

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Abstract: Industry 4.0 revolution offers smart manufacturing; it systematically incorporates production technology and advanced operation management. Adopting these high-state strategies can increase production efficiency, reduce energy consumption, and decrease manufacturer costs. Simultaneously, small and medium-sized enterprises (SMEs) were the backbone of economic growth and development. They still lack both the knowledge and decision-making to verify this high-stage technology's performance and implementation. Therefore, the research aims to define the readiness indicators to assess and support SMEs toward Industry 4.0. The research begins with found aspects that influence the SME 4.0 readiness by using Bibliometric techniques. The result shows the aspects which were the most occurrences such as the Industrial Internet, Cloud Manufacturing, Collaborative Robot, Business Model, and Digital Transformation. They were then grouped into five dimensions by using the visualization of similarities (VOS) techniques: (1) Organizational Resilience, (2) Infrastructure System, (3) Manufacturing System, (4) Data Transformation, and (5) Digital Technology. Cronbach's alpha then validated the composite dimensions at a 0.926 level of reliability and a significant positive correlation. After that, the indicators were defined from the dimension and aspects approach. Finally, the indicators were pilot tested by small enterprises. It appeared that 23 indicators could support SMEs 4.0 readiness indication and decision-making in the context of Industry 4.0.

Keywords: indicators; industry 4.0; readiness

1. Introduction

In the 20th century, Germany declared a new industrial revolution called "Industry 4.0," which meant "High-state Strategies" [1]. It includes smart machines, smart devices, intelligent products, cyber-physical systems (CPS), cloud computing, Internet of Things (IoT), Internet of Service, and big data analysis [2]. These integrate production processes and operations through intelligent work systems, such as automation, robotic devices, and sensors. A smart factory systematically incorporates production technology, marketing, logistics, and operation management. It can replace labor, paper, and documentation, and it supports decision-making. An organization should be flexible [1] and integrate with supply chains [3].

Smart manufacturing is communication between machines to machines and humans [4], a machine or equipment kit that operates a business with the high potential to have products through a self-control operation. It can improve and report the results of the production and the period of self-repair. The machine and device have to have a sensor installed and are programmed by advanced technology, such as robotics and automation machines, and include the transfer part, conveyor, and auto vehicle machine [5]. Then, the product can autonomously track and monitor production information, such as raw material, data storage, source, and integrate all of the value chains at the same system. Moreover, the final product can provide information about their lifecycle [6] and presents the process and information about the step of production and how-to carry out maintenance [6,7]. The technology will replace the workplace and reduce costs in the aspects of energy and jobs. Therefore, the organization will increase production efficiency and business revenue. In this high-state revolution, small and medium-size enterprises (SMEs), namely, "SMEs 4.0."

In addition, the importance of implementing technology to increase efficiency and value creation in small organizations (SMEs) is the main problem. First, there is a lack of knowledge and understanding of the development and improvement of technology in the business [8]. They do not have an awareness of applied technology in production [9]. SMEs cannot evaluate their business to find a gap in technology adaption and are unconcerned about the global and sociality effect [10]. Therefore, the research gap of literature is a limitation in the decision-making in the Industry 4.0 implementation.

According to the systematic literature review, many existing scientific researches are focusing on the implementation of Industry 4.0 and theoretical. They provide answers based on their research interests, which is the domain-specific area [11]. Then, the literature review examines Industry 4.0 readiness factors and indicators for SMEs. These are used to evaluate organizational readiness and Industry 4.0 implementation. Exemplary popularity research is that of Impulse Foundation of Verband Deutscher Maschinen-und Anlagenbau (IMPULS) [12], the University of Warwick [13], Schumacher et al. [14], and Leyh et al. [15], which have developed Industry 4.0 readiness assessment. Therefore, the content of Industry 4.0 management is focused only on sizeable industry with high potential and does not support SMEs' capability scale. [10]. Hence, Chonsawat and Sopadang [9] developed the Smart SMEs 4.0 Readiness model [9] which can support the SMEs' operation in Thailand. The limitation of this model is unclear about the definition and has a similar factor.

Based on this existing research, the literature review presented the dimension or pillar for readiness assessment. Most models or tools use the implement-status qualitative measurement, such as Likert-scales and qualitative self-assessment scores [16]. Therefore, the research motivation would like to define Industry 4.0 readiness indicators for SMEs. The final indicators will assess the organization's preparation and help the decision-maker select the essential dimensions to implement Industry 4.0 in organization and value creation. It can identify weaknesses, effective business processes, and operations that prepare businesses to meet opportunities. That will improve their operations, create new products, services, and processes [17].

The paper is organized as follows—the research background and motivation are presented in Section 1. While Section 2 is literature in the area of Industry 4.0 indicators. Section 3 describes the material and method by using bibliographic analysis. The method can trace the academic field's linkages and trends of development in in-depth descriptive statistics. Section 4 presents the data collection and industry 4.0 aspects development. The result and data analysis are shown in Section 5. Section 6 presents the synthesis of SMEs 4.0 readiness indicators. Section 7 is the case study application, and Section 8 is the discussion and conclusion are in the last section.

2. Research Background

This section includes the literature review, an organization's factors, and barriers for entry to Industry 4.0. Accordingly, this research reviews literature about the aspects influence of Industry 4.0 pillars, factors, and indicators.

2.1. The Industry 4.0 Readiness Aspects and Indicators

Industry 4.0 technology increases production, machine, and operational performance, such as cyber-physical systems, robotics, cloud manufacturing, Internet of Things, big Data, smart devices, and simulation technology. Brooks et al. [18] present the framework with the success factors of the business intelligence. The (1) Business Processes, (2) Technology Infrastructure, (3) Organization Operation and Culture, (4) Employee Skills are the critical elements in Industry 4.0 [18].

They show the success factors are governance, IT, business and partnership, communication about the data and initiatives analytics, business, and IT data quality [18].

Then, Schumacher et al. [14] present the model for assessing Industry 4.0 maturity. They are nine dimensions and 62 items. The dimensions are divided into two concepts: the organizational aspects are (1) Strategy, (2) Leadership, (3) Governance, (4) Culture, and (5) People. The fundamental enable aspects are (6) Products, (7) Customers, (8) Operations, and (9) Technology [14]. The example items in the assessment model are implementation roadmap, business models, digitalization of products, Interdepartmental collaboration, knowledge sharing, cross-company collaboration, technological standards, and machine-to-machine communication [14].

The popularity of Industry 4.0 readiness is developed by IMPULS [12]. This model contains six basic dimensions. (1) Strategy and Organization (2) Smart Factory, (3) Smart Operations, (4) Smart Products, (5) Data-Driven Services, and (6) Employees. The 18 fields are used to measure the indicators, exemplary, strategy, investments, equipment infrastructure, IT systems, cloud usage, IT security, information sharing, share of revenues, and employee skills. They present Industry 4.0 is smarter, faster, more efficient, and has more integration. The manufacturer is obtaining greater potential, which is the technology in this revolution [12]. However, the small companies did not participate in this project.

Similarly, the University of Warwick [13] adopts the readiness assessment tool, which supports the enterprise to enable high flexibility. It provides short time to market by a requirement and improved performance. The dimension is the technology in six dimensions: (1) Products and services, (2) Manufacturing and operations, (3) Strategy and Organization, (4) Supply Chain, (5) Business Model, and (6) Legal Considerations [13]. This assessment includes 37 sub-dimension such as product customization, digital features of products, automation, technology integration, operations data collection, cloud solution usage, IT and data security, resource capability, digital modeling, equipment, strategy, investments, leadership, supply chain integration, and real time tracking. The purpose is to assess its readiness and motivation to the full potential in the Industry 4.0 context [13].

Leyh et al. [19] present the challenge of the enterprise to join the business processes in digitization [15]. This presents the systematic integration maturity model Industry 4.0 by four dimensions. (1) Vertical Integration is about products, machines, and exchange information, while (2) Horizontal Integration is the partners and information flow. (3) Digital Product development is the information that must be forwarded to the next and previous step and organizational system and (4) Cross-Sectional Technology criteria which are service-oriented architecture, cloud computing, big data, and IT security. They have to improve automation, business model, and operation to gain Industry 4.0 [15].

On the other hand, Viharos et al. [20] present the non-comparative, personalized Industry 4.0 readiness measurement. (1) Strategy, which is a resource, company strategies, and competitors. (2) Leadership is Industry 4.0 Management, coordination and business models. (3) Offered Products and Services are individualized products, embedded systems and digitalized products. (4) Customers are a partner with an integrated solution. (5) Company Culture includes employees and stakeholders. (6) People entails employee skill, and motivation. (7) Production Support is about the automatic process, production data, and information sharing. (8) Production Execution is tracking and auto-configuration. (9) Digital Production includes digital simulation, digital forecasts, and lean. It also reflects the position and working in the market and environment in a personalized company.

Gokalp et al. [21] present the development of assessment model for Industry 4.0, a framework for the organization, by providing comprehensive guides and road maps. The model contains the aspect dimensions, which are: (1) Asset Management that includes equipment, cloud computing, IT security, and industrial wireless networks. (2) Data Governance, which is data collection, usage, data analytics, big data, and data-driven services. Next, (3) Application Management is integrated with automation and information systems, (4) Process Transformation is about the planning, and sale and distribution. Finally, (5) Organizational Alignment is the organizational structure and strategy [21].

In addition, Issa et al. [22] present the significant problem of the information deficit of SMEs toward Industry 4.0. They describe that the critical factors are the infrastructure and competence to adapt to the new environment, while the skill of Industry 4.0 is the core of employee improvement. The other essential factors are resources and facilities, knowledge, standards, information security, industrial communication, and controllers. Industry 4.0 can help SMEs to reduce time and process, but they still need to improve their skillset [22].

Kane et al. [23] developed the digital technology in business. They present the (1) Digital Strategy, and (2) Organization Culture that are important for the business transformation. The goal of the organization must include (3) Employee Perception and (4) Leadership [24].

In addition, the previous research of Chonsawat and Sopadang [9] developed the implementation of a maturity model for assessing the readiness for Smart SMEs 4.0 [9]. The model includes five dimensions and 43 sub-dimensions (factors). The dimensions are (1) Manufacturing and Operations, (2) People Capability, (3) Technology-Driven Processes, (4) Digital Support, and (5) Business and Organization Strategies. The model has a confusing meaning, and some of the indicators are duplicated, such as data connection and information sharing factor have an unclear definition.

As a result, all the previous assessment tools present the dimensions or pillars to indicate their readiness. Therefore, this research identifies indicators to assess readiness and implementation.

2.2. The Methodology for Aspects Identification

This section is literature review about the methodology to identify the factor. Table 1 concludes the research methodology that identifies the factors that focus on the successful factors for Industry 4.0 implementation. Hence, the factors and barriers of an organization for entry to industry 4.0 are still popular to develop.

Table 1. Methodology for aspects identification.

Author(s)	Method	Approach
del Río González, 2005 [25]	Interviews	The factors influencing clean technology adoption.
Nemoto et al., 2010 [26]	Literature Review	The factors used to decide to adopt a new technology.
Darbanhosseiniamirkhiz et al., 2012 [27]	Literature Review	The critical factors that influence the adoption of AMTs and identify hurdles and barriers.
Sadeghi et al.,2012 [28]	Fuzzy-AHP	Develop a model to evaluate factors affecting Iranian high-tech SME's success.
Palacios-Marqués et al., 2014 [29]	Structural Equation Modelling (SEM)	Analyzing factors affecting Web knowledge exchange in SMEs.
Bayarçelik et al., 2014 [30]	AHP	Determining innovation factors for SMEs.
Arifin, 2015 [31]	Literature Review	The determinant factors of technology adoption at firm level.
Osorio-Gallego et al., 2016 [32]	Questionnaire	Analyze the factors that influence the adoption of ICT by SMEs.
Hassan, 2017 [33]	Questionnaire research	Factors affecting cloud computing adoption in small and medium enterprises (SMEs).
Raut et al., 2017 [34]	Literature Review and expert opinion	Critical success factors of cloud computing adoption in the MSMEs.
Hsu et al., 2017 [35]	QFD and fuzzy MADM methods	Suggested factors for improving the sustainability SMEs.
Blatz et al., 2018 [36]	Questionnaire	The development of digital maturity level of SMEs.
Danvila-del-Valle et al., 2019 [37]	Bibliometric analysis	Consider human capital and performance by evaluating research on the area of human resources training.

Table 1. *Cont.*

Author(s)	Method	Approach
Sony et al., 2020 [38]	Literature Review	Identifies success factors for implementation of Industry 4.0.
Moeuf et al., 2020 [39]	Delphi	Identifies success factors, risks, and opportunity of Industry 4.0 in SMEs.
Gajdzik et al., 2020 [40]	Bibliometric analysis	Identifying key scientific problems of the sustainable development in Industry 4.0.

The method of literature review and the questionnaire are the tools to develop indicators or factor identification. Simultaneously, the multiple attribute decision-making (MADM) methods are used to evaluate the important factors. At the same time, bibliometric analysis is a popular method to identify trends and factors. Table 2 shows a comparison of the methods for identifying the factors (or aspects). The bibliographic is the systematic analysis method, reduces cognitive bias from the expertise experience, traces the aspects linkages, and reveals the hidden and unexpected aspects.

Table 2. Comparison of method approach.

Method	Systematics	Reduce Cognitive Bias	Trace the Aspects Linkages	Allow the Hidden and Unexpected Aspects
Bibliometric	✓	✓	✓	✓
Expertise	✓			
Interview	✓	✓		✓
Literature	✓	✓		
Questionnaire	✓	✓		

As a result, this research uses bibliometric analysis to define SMEs 4.0 readiness indicators and aspects based on the previous and current literature studies on Industry 4.0, which is the novel content in the industrial aspect. Therefore, the next section presents the research methodology to identify the aspects and correlation test using mathematical tools.

3. Research Design and Methodology

The research objective is to define the indicators to assess the readiness of SMEs' transformation to Industry 4.0. The research methodology aims to define SMEs' 4.0 readiness indicators from the Industry 4.0 aspects. The research steps are shown in Figure 1.

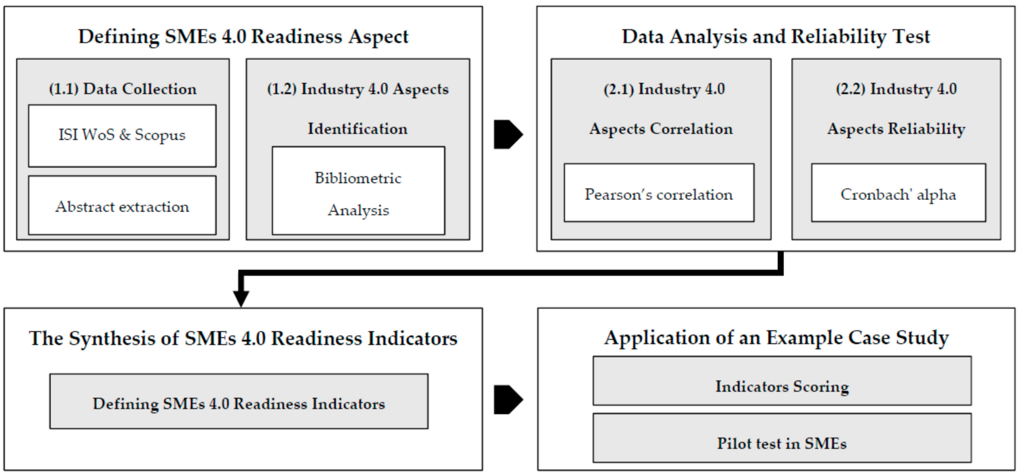

Figure 1. Research methodology.

3.1. Step 1—Defining SMEs 4.0 Readiness Aspects

The first step is defining the critical aspects in readiness of Industry 4.0. As mentioned, the Industry 4.0 aspects were retrieved from the literature review and data collection.

Step 1.1—Data Collection. The researcher collects the abstracts of the articles from two online databases: Web of Science (ISI WoS) and Scopus index. The searching scope is over the years 2008–2020, that is five years before the Industry 4.0 announcement until the present. The database includes Engineering, Computer science, Business management, Environmental science, and related fields. Furthermore, this step refers to the aspects from Chonsawat and Sopadang [9], including the literature in Industry 4.0 readiness, assessment, model, roadmap, factors, and related areas.

Step 1.2—Industry 4.0 Aspects Identification. This research is using bibliometric methods for analysis in the research area. It can analyze research trends, which improves the quality of database analysis [41]. Bibliometrics were first used by Paul Otlet [42] in 1934 and defined as "the measurement of all aspects related to the publication and reading of books and documents". Alan Pritchard used the anglicization version of the bibliography [43] with the first published in 1969 on the topic "Statistical bibliography or bibliography," it defined the term "the application of mathematics and statistical methods" to books and other media of communication.

This research aims to analyze and systematize the aspects of the extant literature on Industry 4.0 readiness. Hence, bibliographic methods are quantitative techniques. That can help reduce the cognitive bias from the researchers' expertise who have previous experiences focusing on familiar domains [44]. Bibliometrics analyzes the data by a distance-based approach from the VOS Viewer software. This software is an easy-to-use presentation software tool that focuses on bibliographic networks [45,46]. The network of keywords can be connected by co-occurrence, co-authorship, citation, co-citation, or bibliographic coupling. When the co-authorship, citation, or bibliographic coupling are working, the number of sources, authors, and countries is received from the bibliographic document. While the documents are working, co-occurrence indicating the number of documents in a keyword occurs [45,47].

We select the keywords co-occurrence and Binary count from the visualization of similarities techniques to collect the keywords from the database [48,49]. After that, the critical keywords are obtained by deleting the irrelevant keywords, using five occurrences, 60% of the relevance term (default), and relevance scores of more than 0.4 [50,51]. In this step, Industry 4.0 aspects are grouped and identified in the dimension (pillars) by visualization of similarities (VOS) techniques.

3.2. Step 2—Data Analysis and Reliability Test

The data reliability and correlation are the fundamental concepts used to define the biases and validate this research.

Step 2.1—Industry 4.0 Aspects Correlation. Pearson's correlation is used to evaluate the data relationship. This can test the relationship between the aspects in the dimensions.

Step 2.2—Industry 4.0 Dimensions Reliability Test. Then, Cronbach's alpha [52] confirms the composite aspects and dimensions. Data analyzed by Cronbach's alpha in which value is more significant than 0.7, have high reliability.

3.3. Step 3—The Synthesis of SMEs 4.0 Readiness Indicators

This step is defining SMEs 4.0 readiness indicators. After step 2 confirms the aspects and dimensions of Industry 4.0 readiness, the researchers defined the indicators from the Industry 4.0 aspects and dimensions (pillars) approach by the systematic literature review. Then, the next step is the indicators score and evaluate the SMEs readiness.

The final step is to implement SMEs 4.0 readiness indicators by a pilot test with the sample small-enterprise case. The researcher interviews the owners in SMEs, which begins with the indicators used to interview the organization's capability. SMEs give the score for their capability in all the indicators by referring from Software Process Improvement and Capability Determination (SPICE) [53–55]. Also, the results of this research will be explained in the next section.

4. Defining SMEs 4.0 Readiness Aspects

This section presents the step to defining the aspects of SME's readiness in Industry 4.0 implementation. It begins with the data collection in Section 4.1, and identification aspects of industry 4.0 in Section 4.2.

4.1. Data Collection

Following the research purpose, in Table 3, we collect the data from two online science databases: Web of Science (ISI WoS) and Scopus index between the years 2008–2020. Thus, this research focuses on the aspects for readiness and success of Industry 4.0 implementation. The keywords for searching are Industry 4.0, Smart manufacturing, Smart factory, Maturity, Readiness, Assessment, Roadmap, Implementation, Strategy, Successful, Critical factor, and Indicator. Finally, this research scanned journal articles and books' abstracts to explore Industry 4.0 readiness and implementation.

Table 3. Keywords parameters.

Database	Scopus, ISI Web of Science
Time Limitation	2008–2020
Category	Engineering; Computer Science; Business Management and Accounting; Decision Sciences; Mathematics; Social Sciences; Materials Science; Energy; Environmental Science and related.
Source	Article; Book and Book Chapter
Language	English
Keywords Search	Industry 4.0, Smart Manufacturing, Smart Factory, Maturity, Readiness, Assessment, Roadmap, Implementation, Strategy, Factor Successful, Critical Factor, Indicator

Also, the database has information such as author name, year, abstracts, and address. The bibliometric analysis uses the abstract from the databases. In this step, the abstract was extracted from the database using an abstract algorithm from the Bibexcel program and integrated data from Web of Science and Scopus index.

4.2. Industry 4.0 Aspects Identifications by Bibliometric Analysis

As a result of the data searching in Table 1, the research obtained a database from the Web of Science of 641 journals, and Scopus of 907 journals. After that, the abstracts' data were extracted amounting to 1541 data and 336 keywords from the co-occurrence in bibliometric analysis. The irrelevant and duplicate keywords are deleted such as academic, fog, and systems. Hence, the researcher selected the 34 aspects from the most occurrences and relevance scores in the interested aspects and literature review. The number of occurrences and VOS's relevance score are shown by Van Eck and Waltman [46]. In terms of the relevance score, this presents the trends of specific keywords that covered all text in the database.

In visualization mapping, aspects are represented by circle labels, while the cluster and their links determine each aspect by color [47]. Accordingly, the research finds 34 aspects, we update the visualization map, and, finally, the research concludes five dimensions (pillars) for SMEs' 4.0 readiness aspects.

Figure 2 presents the relationship and group of the dimensions from the visualization of similarities (VOS) techniques which generate maps using VOS mapping and VOS clustering techniques. These are new alternative techniques to multidimensional sizing approaches [54]. The techniques performed the normalizing co-occurrence frequencies that observed the number of co-occurrences of node (aspects) i and node (aspects) j [43,44] which is called the association strength. There are often significant differences between node in the number of edges per other nodes [56].

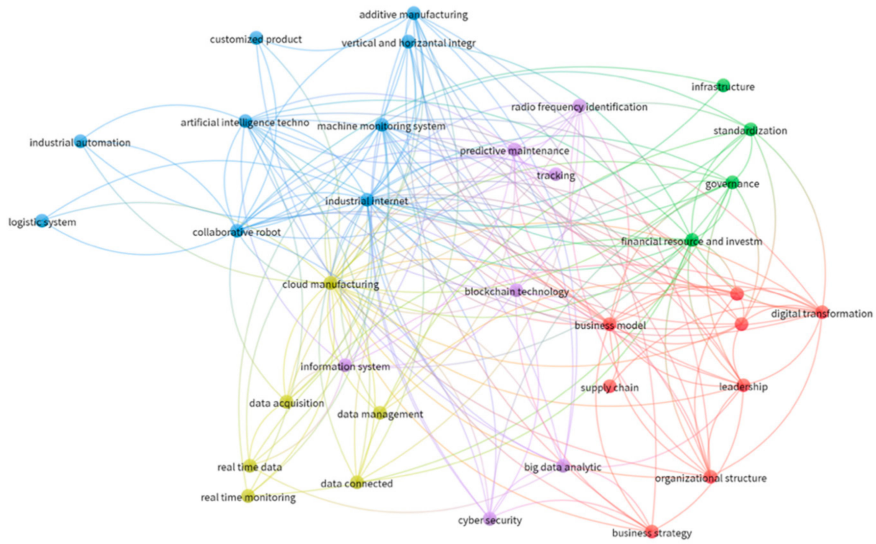

Figure 2. Industry 4.0 Aspects relationship from visualization of similarities mapping.

Table 4 presents the keyword from the bibliographic analysis. Industry 4.0 aspects with the most relevance score are Supply chain management, Infrastructure, Circular economy, Business model, and Data management. These results indicate that supply chain management, such as partnership, stakeholders, and the customer, has the most relevant industry 4.0 development. The infrastructure, real-time data, digital technology, and protection are essential for the data exchange in the operational SMEs toward Industry 4.0.

Table 4. Industry 4.0 Aspects selection keywords from the visualization of similarities techniques.

ID	Aspects	Occurrences	Relevance Score
1	additive manufacturing	28	0.6743
2	artificial intelligence technology	56	0.2877
3	blockchain technology	18	0.4721
4	business model	73	1.4799
5	business strategy	13	0.6441
6	circular economy	17	1.6295
7	cloud manufacturing	153	0.3343
8	collaborative robot	77	0.6114
9	customized product	11	1.3406
10	big data analytic	25	0.3971
11	data acquisition	16	0.888
12	data connected	19	0.7684
13	data management	9	1.4141
14	cybersecurity	7	0.8387
15	digital transformation	56	1.3022
16	financial resource and investment	47	0.7214
17	governance	55	0.6979
18	human resource	15	0.901
19	industrial automation	14	0.7769
20	infrastructure	7	2.0728

Table 4. *Cont.*

ID	Aspects	Occurrences	Relevance Score
21	information system	26	0.6179
22	leadership	54	0.9993
23	logistics system	5	1.0985
24	industrial internet	209	0.2643
25	machine monitoring system	51	0.3855
26	organizational structure	41	0.5835
27	predictive maintenance	55	0.6987
28	radio frequency identification	14	0.3858
29	real time data	13	1.0773
30	real time monitoring	13	0.4867
31	standardization	21	0.7706
32	supply chain management	6	5.0001
33	tracking system	13	1.4012
34	vertical and horizontal integration	15	0.7538

While the occurrence score is the frequency of the keywords that count in the document analysis by binary counting, then the most emerging aspects are the Industrial Internet, Cloud manufacturing, Collaborative robot, Business model, and Digital transformation. These show that the element of Industry 4.0 is the advanced technology and the integration of worker and system integration, and the governance is one of the organization's perceptions that has driven the business toward Industry 4.0. The research also found that organization and business model have most mention in both occurrence and relevance score, meaning that readiness of enterprise is essential to Industry 4.0 implementation.

During the systematic review, expert experience, and bibliometric analysis, the researchers conclude the 34 Industry 4.0 aspect in the dimensions (pillars). Table 5 concludes the aspects and a group of five dimensions in the Industry 4.0 approach.

After the bibliometric analysis, the data of occurrence and each dimension's linkage are used to analyze the next section.

Table 5. Industry 4.0 dimension and aspects.

Dimension/Pillar	Industry 4.0 Contributions	Aspects	Exemplary Publication
Organizational Resilience	The communication with the interdisciplinary department and worker to leadership or manager. Intra-firm and inter-firm departments communication and stakeholders.	• Business Model, • Business Strategy, • Digital Transformation, • Human Resource • Leadership, • Organizational Structure, • Supply Chain Management	Birkel et al., 2019 [10]; Brooks et al., 2015 [18]; Haseeb et al., 2019 [54]; Kiel et al., 2017 [57]; Pereira et al., 2017 [6]; Schumacher et al., 2016 [14]; Zhong et al., 2017 [3]
Infrastructure System	The standard for exchanging data from production and the process have safety, quality/health, and standard regulations.	• Governance, • Infrastructure, • Financial Resource and Investment, • Standardization	Agca et al., 2017 [13]; Braccini et al., 2019 [58]; Guedria et al., 2009 [53]; Kiel et al., 2017 [57]; Lichtblau et al., 2015 [12]; Muller et al., 2019 [59]; Stock and Seliger, 2016 [60]

Table 5. *Cont.*

Dimension/Pillar	Industry 4.0 Contributions	Aspects	Exemplary Publication
Manufacturing System	Reduce lead time, costs, defect rates, heavy labor and incidents. Increase quality of employee satisfaction.	• Additive Manufacturing, • Artificial Intelligence Technology, • Logistics System, • Collaborative Robot, • Customized Product, • Industrial Automation, • Industrial Internet, • Machine Monitoring System, • Vertical and Horizontal Integration	Fatorachian et al., 2018 [61]; Gokalp et al., 2017 [21]; Issa et al., 2017 [22]; Lacoste, 2016 [62]; Lichtblau, 2015 [12]; Lu, 2017 [63]; Pereira et al., 2017 [6]; Kliestik et al., 2020 [64]
Data Transformation	Predictive maintenance and support the decisions-making based on data structure. Optimize resources and reducing environmental impact.	• Blockchain Technology, • Cloud Manufacturing, • Data Acquisition, • Data Connected, • Data Management, • Real Time Data, • Real Time monitoring	Agca et al., 2017 [13]; Chonsawat et al., 2018 [9]; Hofmann et al., 2017 [65]; Kiel et al., 2017 [57]; Lichtblau et al., 2015 [12], Muller et al., 2020 [66]; Qian et al., 2107 [67]
Digital Technology	Business opportunities. Increase time to market. Reduce unwilling to pay sufficient money for products and services. Understand customer problems and expectations	• Data Analytic, • Circular Economy, • Cybersecurity, • Information System, • Radio Frequency Identification, • Tracking System, • Predictive Maintenance	Braccini et al., 2019 [58]; Brettel et al., 2014 [68]; Ciasullo et al., 2013 [69]; Dombrowski et al., 2017 [70]; Leyh et al., 2016 [15]; Muller et al., 2018 [71]; Viharos, 2017 [20]

5. Data Analysis and Reliability Test

Following the research purpose, this section describes dimensions validation result. First, the dimensions correlation is presented in Section 5.1 and the dimension reliability test in Section 5.2.

5.1. Industry 4.0 Diemension and Aspects Corelation

This section describes the result of the research. Pearson's correlation coefficient is used to evaluate the relationship between the data. The data were taken from the occurrence number and the total score link in each node (aspect) is obtained from the bibliometric analysis. The correlation coefficient value ranged between −1 and 1 [49]. While the correlation coefficient value is near 1, −1, that are strongly positive and negative, N = 34. This has a significant positive correlation at 0.05 and 0.01 level (see in Appendix A).

5.1.1. Organizational Resilience

The correlation is positively significant between the aspects of Business Model with Business Strategy, Digital Transformation, Leadership, Organizational Structure, Supply chain management, and Human resource 0.328*, 0.560**, 0.585**, 0.449**, and 0.348* respectively. Similarly, a strong significant positive correlation of Business Strategy and Supply Chain Management at 0.778**.

Then, the Business Strategy has a significant correlation with Digital Transformation, Leadership, and Organizational Structure, which is significant at 0.564**, 0.472**, and 0.488**, respectively. Digital Transformation has a positive correlation with Leadership, Organizational Structure, and Supply Chain Management at 0.612**, 0.677**, and 0.671**. The correlation between Leadership and Supply

Chain Management has a positive significance at 0.522**. Then, Organizational Structure and Supply Chain Management have significance at 0.585**.

Moreover, the Human Resource does not have a positive correlation with the Business Strategy, Digital Transformation, Leadership, Organizational Structure, and Supply Chain Management.

As Human Resource does not have a significance relationship with the other aspects, reject Human Resource. So, the Business Model, Business Strategy, Digital Transformation, Leadership, Organizational Structure, and Supply Chain Management can support SMEs' 4.0 readiness indicators in dimensions of Organizational Resilience.

5.1.2. Infrastructure System

Simultaneously, the relationship of Infrastructure with Financial Resource and Investment, and Standardization correlation is positively significant at 0.457** and 0.361*, respectively. Then the correlation between Financial Resource and Investment correlated with Standardization and has a positive significance at 0.554**. The Governance aspects have a correlation at 0.009, 0.104, and 0.234 with the Infrastructure, Financial Resource and Investment, and Standardization. Because the significant correlation is not found, reject aspects of Governance.

The aspects of Infrastructure, Financial Resource, and Investment, and the Standardization supports the SMEs' 4.0 readiness indicators in dimensions of Infrastructure System are accepted.

5.1.3. Manufacturing Systems

The Logistics System has a positive significant correlation between the Collaborative Robot, Customized Product, Industrial Automation, the Industrial Internet, Machine Monitoring System, and Vertical and Horizontal Integration at 0.451**, 0.895**, 0.689**, 0.562**, and 0.799**, respectively. The Collaborative Robot correlates with Customized Product, Industrial Automation, Industrial Internet and Vertical and Horizontal Integration at 0.534**, 0.746**, 0.435**, and 0.369*, respectively. The correlation between Customized Product with Industrial Automation, Industrial Internet, Machine monitoring system, and Vertical and Horizontal Integration at 0.764**, 0.426**, 0.780**, and 0.526**. While, Industrial Automation correlation with Industrial Internet, Machine Monitoring System, and Vertical and Horizontal Integration at 0.424**, 0.571**, and 0.634**.

In contrast, Additive Manufacturing, Artificial Intelligence Technology have a negative correlation, while Machine Monitoring System, and Vertical and Horizontal Integration have no significant relationship. So, reject Additive Manufacturing, Artificial Intelligence Technology, Machine Monitoring System, and Vertical and Horizontal Integration.

As a result, accepted that the Logistics System, Collaborative Robot, Customized Product, Industrial Automation, and Industrial Internet aspects support the SMEs' 4.0 readiness indicators in the dimensions of Manufacturing Systems.

5.1.4. Data Transformation

In addition, the Cloud Manufacturing and Blockchain Technology have a significant correlation at 0.620**. Cloud Manufacturing correlation with Data Acquisition at 0.323*, Data Connected at 0.439**, and correlation with Real Time Data is 0.321*. Simultaneously, the correlation of Data Acquisition with Data Connected, and Real Time Data were significant at 0.581**, 0.469**, and 0.658**, respectively. Data Connected and Real Time Data correlate at 0.503**.

Conversely, Blockchain Technology, and Real Time Monitoring have no significant correlation with the Data Management, reject Blockchain technology, Data management, and Real Time Monitoring.

Thus, the accepted Cloud Manufacturing, Data Acquisition, Data Connected, and Real Time Data support the SMEs' 4.0 readiness indicators in dimensions of Data Transformation.

5.1.5. Digital Technology

From the result of Big Data Analytics correlates with Circular Economy, Information Systems, Radio Frequency Identification, Tracking Systems, Predictive Maintenance, and Cybersecurity significantly at −0.081, 0.585**, 0.692**, 0.473**, 0.432** and 0.579**, respectively. Moreover, the Information systems with Circular Economy, Radio Frequency Identification, Tracking Systems, Predictive Maintenance, and Cybersecurity correlate at −0.091, 0.413**, 0.387*, 0.389* and 0.413**, respectively. In the correlation of Tracking Systems with Circular Economy, Information Systems, Radio Frequency Identification, Predictive Maintenance and Cybersecurity is at 0.036, 0.387*, 0.721**, 0.462** and 0.572**, respectively. Furthermore, Predictive Maintenance correlate with Circular Economy, and Cybersecurity at 0.084, 0.336*. The Circular Economy have a negative correlation and no significant relationship with Radio Frequency Identification have, reject Circular Economy and Radio Frequency Identification. Finally, accepted that the aspects of Big Data Analytics, Information Systems, Tracking Systems, Predictive Maintenance, and Cybersecurity support the SMEs' 4.0 readiness indicators in dimensions of Digital Literacy.

Therefore, the researcher confirms that 23 aspects can develop SMEs' 4.0 readiness indicators. It can assess organizational readiness and assist decision-makers in selecting critical dimensions to implement Industry 4.0. The composite of SMEs 4.0 readiness dimension will be validated in the next section.

5.2. *Industry 4.0 Dimension Reliability Test*

The research integrated the five dimensions and 23 aspects into the SMEs' 4.0 readiness. This can evaluate the readiness and organize implementation to achieve the long-term capability and increase the competitiveness opportunity.

Table 6 shows the result of the data reliability of Cronbach's alpha. The overall 23 aspects have Cronbach's alpha 0.926. The dimensions of Organizational resilience, Infrastructure system, Manufacturing system, Data transformation, and Digital literacy have Cronbach's alpha values of 0.898, 0.757, 0.780, 0.740, and 0.840, respectively. So, the dimensions have high values of more than 0.7. It means the data have reliability. Therefore, the dimensions can integrate to SMEs' 4.0 readiness indicators. The next section provides the synthesis of SMEs' 4.0 readiness indicators, concluding the SMEs' 4.0 readiness indicator and definition.

Table 6. Data reliability validation.

Dimensions	Cronbach's Alpha	N of Items
All aspects	0.926	23
Organizational Resilience	0.898	6
Business Model		
Business Strategy		
Digital Transformation		
Leadership		
Organizational Structure		
Supply Chain Management		
Infrastructure System	0.757	3
Infrastructure		
Financial Resource and Investment		
Standardization		
Manufacturing System	0.780	5
Logistics System		
Collaborative Robot		
Customized Product		
Industrial Automation		
Industrial Internet		

Table 6. *Cont.*

Dimensions	Cronbach's Alpha	N of Items
Data Transformation	0.740	4
Cloud Manufacturing		
Data Acquisition		
Data Connected		
Real Time Data		
Digital Technology	0.840	5
Big Data Analytics		
Information System		
Tracking System		
Predictive Maintenance		
Cybersecurity		

6. The Synthesis of SMEs 4.0 Readiness Indicators

This research defines essential indicators in Industry 4.0 readiness for SMEs by using the bibliometric method. Methodology is keywords-occurrence analysis and clustering. The database is 1541 publications form Web of Science and Scopus database. Then, the research found 34 aspects from analyses. After that, the finding of dimension, there are validation by using Pearson's correlation and Cronbach's alpha. The dimensions have Cronbach's alpha equal to 0.926 and a significant positive Pearson's correlation. The result from analysis shows all the aspects and dimensions that are important to assess SMEs' 4.0 readiness in preparing for Industry 4.0. The output shows the important 23 aspects were grouped into five dimensions.

The example of indicators presents in Table 7, the SMEs readiness indicators defined from the dimension and aspects by systematic literature and Industry 4.0 approach. The SMEs can also identify the indicator to accord their activity and operation in the context of the 23 aspects and five dimensions.

Table 7. SMEs 4.0 readiness indicators.

Dimension	Aspects	Readiness Approach	Example Indicators
Organizational Resilience	Business Model	Digital business model and service which implications Industry 4.0 [59].	# Level of ability to achieving to digital platform
	Business Strategy	A strategy, plan, and plan for long-term business competition [72,73].	% of achieving a strategy goal # Level of ability to implement Industry 4.0 strategy across the business
	Digital Transformation	Digital in designing to formulate creating marketing products [74].	# Level of ability to create digital product value % of customer from digital marketing
	Leadership	An awareness of SME leadership [75].	# Level of ability to lead achieve a goal % of Industry 4.0 expertise leadership
	Organizational Structure	The organizational structures open and flexible, environment and culture [76]	# Level of adjustment for a change % of worker achieve Industry 4.0 goal
	Supply Chain Management	Co-creation value of internal and external stakeholders [77].	# Level of cooperation with stakeholders % of real-time integrated planning

Table 7. *Cont.*

Dimension	Aspects	Readiness Approach	Example Indicators
Infrastructure System	Infrastructure	An equipment infrastructure is an important requirement [78].	% of capital in infrastructure assets
	Financial Resource and Investment	Financial and investment capital improve products or processes [79].	% of capital R&D % of capital allocated in Industry 4.0 project
	Standardization	Standardizations in operation, product and process [80].	% of standards for digital communication channels % of Standard equipment and production
Manufacturing System	Logistics System	The transport system in different operation area [81].	% of automated the material containers and carriers at workstations
	Collaborative Robot	Industrial robots working alongside humans to share their workload [82].	% of labor productivity % of production efficiency # ability of robotic and human interaction
	Customized Product	A customized product and flexible production [83].	% of customized product % of adjusting the customized production
	Industrial Automation	An adaptation of automated and robotic manufacturing [84].	% of automated production # OEE
	Industrial Internet	A solution to provider in automation and production systems of data collection and data transmission [85].	% of machines automatic exchange data % of the machine and system integrated cross area
Data Transformation	Cloud Manufacturing	Technology-driven flexible computing, capabilities for big data and intelligent applications [86].	% of data storage on cloud # cloud storage capacity
	Data Acquisition	A collect data from modern while still directly connected to the sensor [87].	% of automatic data collection % of real-time data collection
	Data Connected	Data sharing among the resources [88].	% of automatic data connection % of real-time data connection
	Real Time Data	Real-time data management [89].	% of automatic real-time data monitoring # Level of capability of real-time data
Digital Technology	Big Data Analytics	Data analysis and support to use and manage large amounts of data [90].	% of data solution implemented across business. # Level of data analytics capability.
	Information System	Interaction between software and business analysis functionality [91].	% of usage automatic transfer order to production
	Tracking System	Real-time object detection and tracking [92].	% of real-time automatic tracking % of material deliveries is monitored in real-time
	Predictive Maintenance	The predictive maintenance to increase productivity and machine quality [93].	% of routine machine # rate of fixing broken
	Cybersecurity	Data security and IT security [94].	% of replacement software % of area implemented the IT security

6.1. Organizational Resilience

This dimension is a readiness in terms of organizational and partner cooperation. It is a communication between the interdisciplinary department and workers; accordingly, the management and organization strategies that support Industry 4.0 principles.

The first indicator is the Business Model. That is the new digital Business model that implicates Industry 4.0. It combines new external knowledge with internal activities and innovations that analyze the design of newly established Business models in response to the emergence of Industry 4.0. Then is the Business Strategy indicator, which is a strategic plan for long-term business competition and creates collaboration value. Industry 4.0 enables industrial production to make intelligent automation and complex system, which solves the industry's challenges in the future. The indicator Digital Transformation is the introduction of digital technology in operations. These designs or create marketing products. It supports and connects decision-making with data and information, which increases decision-making and recommendation to formulate strategies.

Additionally, the ***Leadership*** indicator is a crucial factor influencing the business model in an intelligent factory: management and leadership. An awareness of SME leadership and employees is vital to implement and deploy in Industry 4.0. The Organizational Structure indicator, which is about the companies and factories, is beginning to prepare the organizational structures and new technology to be used in the production process. It is a process to implement and create an open and flexible organizational environment and culture. Finally, the Supply Chain Management indicator is a strategy of co-creation value. It recognizes the readiness for changes in Industry 4.0, from external factors related to internal factors.

6.2. Infrastructure System

Infrastructure system readiness comprises the infrastructure, investment and standards for exchanging data from production, and the process. It has safety, quality/health, and standard regulations achieved to enable social and economic perception development.

It appears that the Infrastructure indicator is formulating the Industry 4.0 strategy; an equipment infrastructure is a vital requirement. Therefore, the Financial Resource and Investment indicator supports the assessment of the organization's capacity and the changes necessary to ensure that they are aware of their investment, which shows business organizations' efficiency. It improves their long-term competitiveness and project management. Similarly, the Standardization indicator is one of the roles in implementing the Industry 4.0 concept. It has been proven that the formation of the modernization requires standardizations in operation, product, and process.

6.3. Manufacturing System

Manufacturing system readiness entails production processes and operations that use advanced technology, which integrates the systematic process and worker collaboration.

To support the dimension, the first indicator of this dimension is the Logistics System. It is crucial and one of the broad parts in the Industry 4.0 industry. It is a logistics transport system that links all the companies in the manufacturing systems, in which a different operation area works every day in an automatic model. The next indicator is Collaborative Robot also known as human–machine interaction. That is a new generation of industrial robots working alongside humans to share their workload. It is relevant and generic in Industry 4.0, offering to apply to manufacture scenarios.

Simultaneously, the indicator of Customized Product is smart production, as a customized product shows that the proposed approach can achieve smart manufacturing. Furthermore, the Industrial Automation indicator is an automated machine and robotic technology. It is the main developed activity for SMEs' implementation of Industry 4.0. Additionally, the Industrial Internet indicator is the Machine Communication of Things technologies which are solutions driven by digitalization in many areas, especially in industrial automation and production systems. Also, it can be a provider of data collection and data transmission.

6.4. Data Transformation

The data transformation readiness dimension involves implementing data and information to support production and operation activities; that is, optimizing resources and reducing environmental impact.

First, Cloud Manufacturing indicator is a technology-driven capability for Big Data in Industry 4.0. This intelligent application provides powerful flexible computing. It has a role in various manufacturing processes, manufacturing design, engineering, production, and marketing. So, the Data Acquisition indicator is industrial storage units that can collect data from modern while still directly connected to the sensor. It integrates with the Industrial Internet in developing context-aware systems and information provision.

Moreover, the Data Connected indicator is data sharing among the shop floor and network sensors' resources. It adjusts the production schedule for the proper implementation of the project. The final indicator is Real Time Data. The era of Industry 4.0 is a wide variety of data, which will lead to accurate and real-time data management. All production decisions are optimized based on real-time data from equipment and operation.

6.5. Digital Technology

The Digital Technology readiness dimension is digital technology and analytics that supports corporate activities. This dimension can support and reduce the cost of production and services and understand customer problems and expectations.

The first indicator is the Big Data Analytics. It is data analysis and real-time decision-making, which positively impacts efficiency. It can support companies to use and manage large amounts of data as decision support. Additionally, the Information System indicator provides full, scalable, error-resistant data pipelines for integration, processing, and industrial data equipment analysis. This can create interaction between software and business analysis functionality.

Similar to the Tracking System indicator is real-time object detection and tracking. It shows the basis of intelligent manufacturing for Industry 4.0 applications. It is a flexible and fully integrated operation by identifying and tracking objects that can leverage constant data from operations and production systems, just as the Predictive Maintenance indicator in the manufacturing, industry achieves the predictive maintenance of machine tool systems to increase productivity confidence and improve machine quality. The data ecosystem will be presented with the implementation of fault detection and diagnosis. Finally, the Cybersecurity indicator is to protect the data and information. That is, security techniques must be implemented in an individual system and cloud solution.

As shown above, this research presented SMEs' readiness indicators for Industry 4.0 implementation. It shows that the indicator has a significant influence, opportunities, and challenges on SMEs' tendency toward Industry 4.0. The example application of the SMEs' 4.0 readiness indicators is presented in the next section.

7. Application of an Example Case Study

This section presents the example of application of indicators. The Section 7.1 describes the score to indicate the readiness of SMEs in Industry 4.0, and Section 7.2 is the application of an example case study.

7.1. Indicators Scoring

Thus, the calculation of the indicators is as shown in equation (1). The individual indicators can be divided into a rating score [0, 100]% from Software Process Improvement and Capability Determination

(SPICE) [53–55]. In the context of this research, the SMEs' 4.0 readiness indicators, all the indicators have generality and are assumed to have equal weight.

The indicators demonstrate the step of Figure 3, which interviews the company by using 23 indicators from Table 7. The indicators' score will be transformed into (0–1) scale, 0 equals no capability, and 1 is fully capable. Then, the average indicators score is present in Equation (1).

$$\text{Average Indicators Score} = \left(\frac{1}{n}\sum \text{indicator(i)}\right) \times 100\% \quad (1)$$

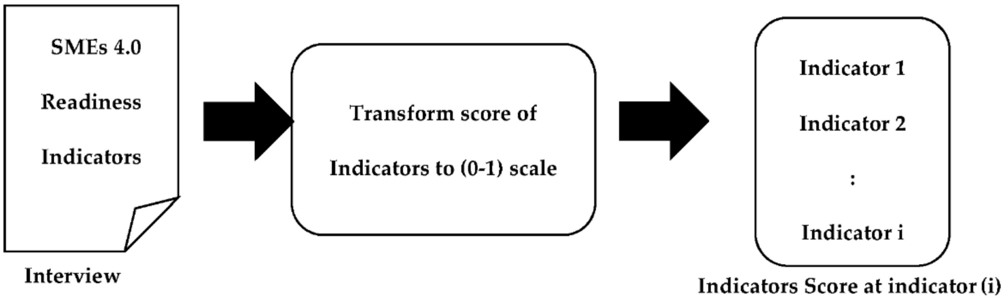

Figure 3. SMEs 4.0 readiness indicators score.

When indicator (i) is the capability indicator score at indicator i, n_i is the number of indicators, n = 23. The score Si is the score from an interview of the organization capability with the capability score of the SPICE level.

The score from Equation (1) can be explained as follows. SPICE capability presents the score as [0, 15]% mean that organization is not achieved. The systems interoperate ad-hoc with other systems, although, it is still constrained and depends on the capabilities of the organization's human skills. The operation is not on strategies and techniques. The IT infrastructure has primary devices that can exchange simple electronic information. Next the score of [16, 50]% is partially achieved. The interoperability of the system provides the collaboration with other systems. The data, services, and processes are managed, which are standard formats. It is possible to adapt the service or business with the organization and environmental change. The worker is trained by the performance of personnel skills and can adjust when the business is changed. Then, the score rank in [51, 80]% is achieved. It has achieved some degree of flexibility that organizations can exchange knowledge and support collaboration with partners that have protective data and security. The interoperability system can collaborate with other systems and partners without the necessity to re-engineer. Finally, the score of [81, 100]% is fully achieved. It is the highest capability level, that is interoperability and continuous improvement. It supports organizations to operate in a fully dynamic way networked with partnership and stakeholders. At the same time, it can adapt to rapidly changing challenges and opportunities in the business. The application of the SMEs' 4.0 readiness indicators is presented in the next section.

7.2. Example of Application

In order to determine the interoperability of indicators, the researcher shows an example which is used to make the use of SMEs' 4.0 Readiness Indicators. The sample company is a small enterprise size in Thailand, which is conducted in the plastics industry. The product is waterproof plastic shoes. The registered capital is around 32k (USD), and exports 10% of the production. They have 25 workers in the organization, 10 employees, and 15 labor in the production line. So, the 23 aspects were used to interview the owner by the indicator's capability, and the score is presented in the Table 8.

Table 8. Example of SMEs 4.0 readiness indications score.

Dimension	Aspects	Indicators	Score
Organizational Resilience	Business Model	# ability to achieving to digital platform	2 *
	Business Strategy	% of achieving a strategy goal	20%
		# ability to implement Industry 4.0 strategy across the business	20%
	Digital Transformation	% of customer from digital marketing	10%
	Leadership	# ability to lead achieve a goal	3 *
	Organizational Structure	% of worker achieve Industry 4.0 goal	40%
	Supply Chain Management	% of real-time integrated planning	20%
Infrastructure System	Infrastructure	% of capital in infrastructure assets	40%
	Financial Resource and Investment	% of capital allocated in the Industry 4.0 project	60%
	Standardization	% of Standard equipment and production	60%
Manufacturing System	Logistics System	% of automated the material containers and carriers at workstations	10%
	Collaborative Robot	# ability of robotic and human interaction	1 *
	Customized Product	% of customized product	20%
	Industrial Automation	% of automated production	20%
	Industrial Internet	% of production machines automatic exchange data	20%
Data Transformation	Cloud Manufacturing	% of data storage on cloud	10%
	Data Acquisition	% of automatic data collection % of real-time data collection	10% 20%
	Data Connected	% of real-time data connection	10%
	Real Time Data	% of automatic real-time data monitoring	20%
Digital Technology	Big Data Analytics	% of data solution implemented across business	10%
	Information System	% of usage automatic transfer order to production	20%
	Tracking System	% of real-time automatic tracking	10%
	Predictive Maintenance	% of routine machine	60%
	Cybersecurity	% of area implemented the IT security	10%

* ability score is 1–5 point which 1 is low capability and 5 is fully capability.

After the indicator interview, the indicator's score is transformed into the 0–1 scale and then the score is calculated from Equation (1). From the example of SMEs' 4.0 Readiness Indications, the average indicators score is shown in Figure 4.

$$\text{Average Indicators Score} = \frac{1}{23}(0.4 + 0.2 + 0.1 + 0.6 + 0.4 + 0.2 + 0.4 + 0.6 + 0.6 + 0.1 + 0.2 + 0.2 + 0.2 + 0.2 + 0.1 + 0.15 + 0.1 + 0.2 + 0.2 + 0.1 + 0.2 + 0.1 + 0.6 + 0.1) \times 100\% = 26.3\%$$

Accordingly, the score of SMEs' 4.0 Readiness in this case is 26.3%. The capability of this case partially achieves Industry 4.0 activity.

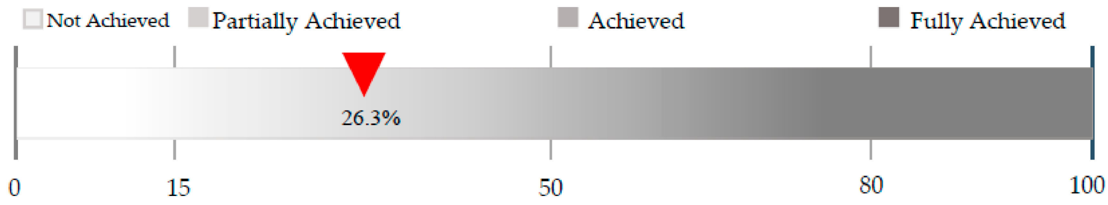

Figure 4. SMEs 4.0 readiness average indicators score.

The company has interoperability of the system, which provides collaboration. Some of the infrastructure and operations can be connected with other systems. The data exchange and process are standard formats. The organization is ready to adapt to business changes and competition opportunities. Meanwhile, the score in the Manufacturing System, Data Transformation, and Digital Technology dimension are the lowest capability and most significant gap to achieve Industry 4.0. Furthermore, the Financial resource and investments are ready for capital in the Industry 4.0 project, which are the essential readiness indicators to achieve Industry4.0.

8. Discussion

This research generates a comprehensive overview of research topics, particularly the process of developing and validating Industry 4.0 indicators. Meanwhile, this research may be a good starting point for future research to identify the appropriate study indicators. Moreover, SMEs can verify the aspects of relevant indicators that support organizations to produce practically useful results.

Based on the bibliometrics analysis, science articles about the Industry 4.0 assessment and aspects are a popular topic. However, there is a lack of quantitative assessment and practical indicator developments, which concluded in the research background. To summarize the research findings, this research contributes to filling in this gap by investigating, describing, and evaluating the structure in Industry 4.0 aspects and quantitative indicators.

First, the articles and literature are collected from the Web of Science and Scopus database. The research found critical 34 aspects for supporting Industry 4.0. The indications can also be identified from dimensions by Bibliometric techniques, which method is the systematic analysis, can reduce cognitive bias, and traces the aspects linkages [44]. The result showed that 23 aspects have a significant positive correlation and high reliability in Cronbach's alpha at 0.926 level.

This research presents the first dimension: the organization's flexibility, operation, and strategies for the Industry 4.0 implementation [9,54]. The aspects indicators are Business Model, Business Strategy, Digital Transformation, Leadership, Organizational Structure, and Supply Chain Management, grouped in the Organizational Resilience dimension. The standard of the production, process, and health are indicated by the Financial Resource and Investment, Infrastructure, and Standardization [57,58,95]. These are grouped in the Infrastructure System's dimension. Then, the Manufacturing System dimension is the aspect of the Collaborative Robot, Customized Product, Industrial Automation, Industrial Internet, and Logistics System, which can indicate the intelligent manufacturing and operation [9]. The data supported operations that include Cloud Manufacturing Data Acquisition, Data Connected, and Real-Time Data, which are in the Data Transformation dimension. Finally, the Digital Technology dimension is digital support business opportunity and management [58,69,95]. The indicator is the Big Data Analytics, Cybersecurity, Information System, Predictive Maintenance, and Tracking System aspects, as shown in Figure 5.

Similarly, the assessment develops by the Impulse Foundation of Verband Deutscher Maschinen-und Anlagenbau (IMPULS) [12] and the University of Warwick [13] or the previous tools. They have a similar dimension (pillars) that can support the Industry 4.0 implementation. Even so, some of these previous readiness assessments are not supporting and cover SMEs capability.

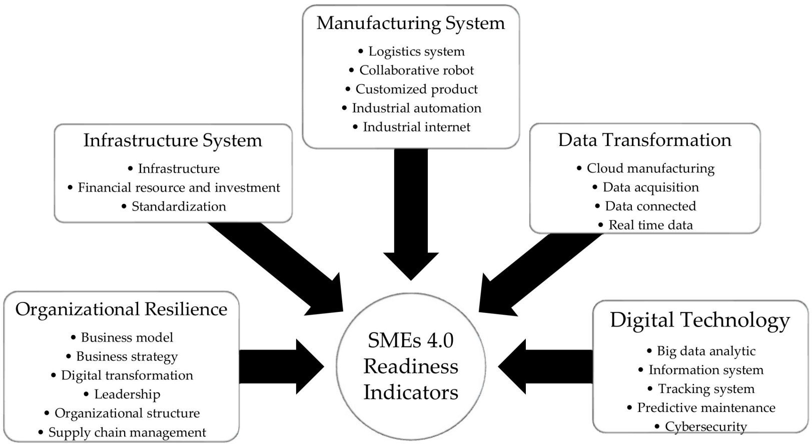

Figure 5. The aspect of SMEs 4.0 readiness indicators.

After that, the researcher implemented the indicators in a small company. As a result of the indicators test, it was found that the tool could support decision-making and specify the alternatives of SMEs' 4.0 readiness development. Indicators can report the readiness and assist the organization toward Industry 4.0 implementation. These readiness assessments are supporting and covered in SMEs.

From comparison with the existing tools, IMPULS [12], the University of Warwick [13], Leyh et al. [15], Schumacher et al. [14], and Gokalp et al. [21], use the dimension or pillars present in the qualitative assessment. Although, this research presented the indicators by using quantitative measurement, which have an accurate assessment. Schumacher and Shin [16] developed the quantitative indicator for monitoring systems performance in industrial digitalization. This research also presents a significant relationship between the indicator and their composition reliability from the quantitative techniques.

Finally, the analysis result confirms that this research aspect can indicate the SMEs' readiness to implement Industry 4.0. That suggests the importance of being able to make rational, correct decisions [96]. It enables decision-makers to verify performance [97] and diagnose problems in organizational operation. Furthermore, the example of the application provided results of readiness measurements, which are based not only on the recommendations result but also on the initial business goal. Additionally, SMEs have to apply the Industry 4.0 context related to their operation and process.

9. Conclusions

Industry 4.0 is an advanced technology that can improve performance efficiency. At the same time, SMEs are the primary economic growth while they have a low capacity. Thus, the research had to define the indicator to support SMEs in closing this gap and assisting in deciding on Industry 4.0 implementation.

This research had made the contributions to the framework of Industry 4.0 indicators development. The research found the aspects that influence SME 4.0 readiness which can group the aspect into dimensions by keyword co-occurrence analysis and visualization of similarities clustering. After that, the aspects and dimensions had to validation. Pearson's correlation tested the result is a significant positive correlation and high reliability in Cronbach's alpha. Finally, the indicators were defined from these dimensions' aspects approach and the pilot tests.

The research also contributes to SMEs, which present the SMEs' 4.0 Readiness Indicators that will enable decision-makers to verify performance to make rational decisions. This can identify the readiness of SMEs and support decision-makers to implement Industry 4.0.

The limitation is that this research has tested the application with a simple example. Future research will develop decision-making in selecting the priority of implementation. Then, the researcher will develop the indicators to cover more the activity in the future of industry aspects and implement the assessment with more SMEs case.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Pearson's correlation.

Organization Resilience		Business Model	Business Strategy	Supply Chain Management	Digital Transformation	Leadership	Organizational Structure	Human Resource
Business Model	Pearson Correlation	1	0.328 *	0.465 **	0.560 **	0.449 **	0.585 **	0.348 *
	Sig. (1-tailed)		0.029	0.003	0.000	0.004	0.000	0.022
Business Strategy	Pearson Correlation	0.328 *	1	0.778 **	0.564 **	0.472 **	0.488 **	−0.066
	Sig. (1-tailed)	0.029		0.000	0.000	0.002	0.002	0.354
Supply Chain Management	Pearson Correlation	0.465 **	0.778 **	1	0.671 **	0.522 **	0.536 **	0.072
	Sig. (1-tailed)	0.003	0.000		0.000	0.001	0.001	0.343
Digital Transformation	Pearson Correlation	0.560 **	0.564 **	0.671 **	1	0.612 **	0.677 **	0.182
	Sig. (1-tailed)	0.000	0.000	0.000		0.000	0.000	0.151
Leadership	Pearson Correlation	0.449 **	0.472 **	0.522 **	0.612 **	1	0.779 **	0.105
	Sig. (1-tailed)	0.004	0.002	0.001	0.000		0.000	0.278
Organizational structure	Pearson Correlation	0.585 **	0.488 **	0.536 **	0.677 **	0.779 **	1	0.140
	Sig. (1-tailed)	0.000	0.002	0.001	0.000	0.000		0.215
Human resource	Pearson Correlation	0.348 *	−0.066	0.072	0.182	0.105	0.140	1
	Sig. (1-tailed)	0.022	0.354	0.343	0.151	0.278	0.215	

* Correlation is significant at the 0.05 level (1-tailed). ** Correlation is significant at the 0.01 level (1-tailed).

Table A2. Pearson's correlation.

Infrastructure System		Infrastructure	Financial Resource and Investment	Standardization	Governance
Infrastructure	Pearson Correlation	1	0.457 **	0.361 *	0.009
	Sig. (1-tailed)		0.004	0.020	0.480
Financial Resource and Investment	Pearson Correlation	0.457 **	1	0.554 **	0.104
	Sig. (1-tailed)	0.004		0.000	0.280
Standardization	Pearson Correlation	0.361 *	0.554 **	1	0.234
	Sig. (1-tailed)	0.020	0.000		0.092
Governance	Pearson Correlation	0.009	0.104	0.234	1
	Sig. (1-tailed)	0.480	0.280	0.092	

* Correlation is significant at the 0.05 level (1-tailed). ** Correlation is significant at the 0.01 level (1-tailed).

Table A3. Pearson's correlation.

Manufacturing System		Additive Manufacturing	Artificial Intelligence Technology	Logistics System	Collaborative Robot	Customized Product	Industrial Automation	Industrial Internet	Machine Monitoring System	Vertical and Horizontal Integration
Additive Manufacturing	Pearson Correlation	1	−0.181	−0.092	−0.249	−0.104	−0.140	−0.313*	−0.092	−0.040
	Sig. (1-tailed)		0.152	0.302	0.078	0.278	0.215	0.036	0.303	0.415
Artificial Intelligence Technology	Pearson Correlation	−0.181	1	0.819 **	0.427 **	0.821 **	0.742 **	0.408 **	0.710 **	0.733 **
	Sig. (1-tailed)	0.152		0.000	0.006	0.000	0.000	0.008	0.000	0.000
Logistics System	Pearson Correlation	−0.092	0.819 **	1	0.451 **	0.895 **	0.689 **	0.295 *	0.562 **	0.799 **
	Sig. (1-tailed)	0.302	0.000		0.004	0.000	0.000	0.045	0.000	0.000
Collaborative Robot	Pearson Correlation	−0.249	0.427 **	0.451 **	1	0.534 **	0.746 **	0.435 **	0.235	0.396 *
	Sig. (1-tailed)	0.078	0.006	0.004		0.001	0.000	0.005	0.090	0.012
Customized Product	Pearson Correlation	−0.104	0.821 **	0.895 **	0.534 **	1	0.746 **	0.426 **	0.526 **	0.780 **
	Sig. (1-tailed)	0.278	0.000	0.000	0.001		0.000	0.006	0.001	0.000
Industrial Automation	Pearson Correlation	−0.140	0.742 **	0.689 **	0.746 **	0.746 **	1	0.424 **	0.643 **	0.571 **
	Sig. (1-tailed)	0.215	0.000	0.000	0.000	0.000		0.006	0.000	0.000

Table A3. *Cont.*

Manufacturing System		Additive Manufacturing	Artificial Intelligence Technology	Logistics System	Collaborative Robot	Customized Product	Industrial Automation	Industrial Internet	Machine Monitoring System	Vertical and Horizontal Integration
Industrial Internet	Pearson Correlation	−0.313 *	0.408 **	0.295 *	0.435 **	0.426 **	0.424 **	1	0.124	0.234
	Sig. (1-tailed)	0.036	0.008	0.045	0.005	0.006	0.006		0.243	0.099
Machine Monitoring System	Pearson Correlation	−0.092	0.710 **	0.562 **	0.235	0.526 **	0.643 **	0.124	1	0.482 **
	Sig. (1-tailed)	0.303	0.000	0.000	0.090	0.001	0.000	0.243		0.003
Vertical and Horizontal integration	Pearson Correlation	−0.040	0.733 **	0.799 **	0.396 *	0.780 **	0.571 **	0.234	0.482 **	1
	Sig. (1-tailed)	0.415	0.000	0.000	0.012	0.000	0.000	0.099	0.003	

* Correlation is significant at the 0.05 level (1-tailed). ** Correlation is significant at the 0.01 level (1-tailed).

Table A4. Pearson's correlation.

Digital Literacy		Big Data Analytics	Circular Economy	Information System	Radio Frequency Identification	Tracking System	Cybersecurity	Predictive Maintenance
Big Data Analytics	Pearson Correlation	1	−0.081	0.585 **	0.692 **	0.473 **	0.579 **	0.432 **
	Sig. (1-tailed)		0.325	0.000	0.000	0.002	0.000	0.005
Circular Economy	Pearson Correlation	−0.081	1	−0.091	0.168	0.036	−0.152	0.084
	Sig. (1-tailed)	0.325		0.305	0.171	0.420	0.195	0.318
Information System	Pearson Correlation	0.585 **	−0.091	1	0.413 **	0.387 *	0.413 **	0.398 **
	Sig. (1-tailed)	0.000	0.305		0.008	0.012	0.008	0.010
Radio Frequency Identification	Pearson Correlation	0.692 **	0.168	0.413 **	1	0.721 **	0.503 **	0.634 **
	Sig. (1-tailed)	0.000	0.171	0.008		0.000	0.001	0.000

Table A4. *Cont.*

Digital Literacy		Big Data Analytics	Circular Economy	Information System	Radio Frequency Identification	Tracking System	Cybersecurity	Predictive Maintenance
Tracking System	Pearson Correlation	0.473 **	0.036	0.387 *	0.721 **	1	0.572 **	0.462 **
	Sig. (1-tailed)	0.002	0.420	0.012	0.000		0.000	0.003
Cybersecurity	Pearson Correlation	0.579 **	−0.152	0.413 **	0.503 **	0.572 **	1	0.336 *
	Sig. (1-tailed)	0.000	0.195	0.008	0.001	0.000		0.026
Predictive Maintenance	Pearson Correlation	0.432 **	0.084	0.398 **	0.634 **	0.462 **	0.336 *	1
	Sig. (1-tailed)	0.005	0.318	0.010	0.000	0.003	0.026	

* Correlation is significant at the 0.05 level (1-tailed). ** Correlation is significant at the 0.01 level (1-tailed).

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