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Developing I4.0 Readiness Index for Factory Operation in Indonesia to Enhance INDI 4.0

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Abstract— **Adopting Industry 4.0 (I4.0) is an effort to gain competitiveness through technological innovation for enhancing productivity and efficiency. Indonesia left behind in launching the policy timeline of the I4.0 initiative, compared to Singapore, Thailand, Malaysia, and Vietnam. In an official government report, Indonesia's I4.0 index showed a low score at an average of 1.992 (scale 0 to 4). Indonesia designed INDI 4.0 (Industry 4.0 readiness index Indonesia) in 2018 to prepare industry readiness. It lacks accuracy and is less comprehensive in capturing I4.0 readiness, especially in the factory operation aspect. INDI 4.0 just provides very few questions to capture extensive information in measuring I4.0. This study aimed to develop a comprehensive I4.0 index by enhancing INDI 4.0 in the factory operation aspect. By exploring issues in the I4.0 readiness index, the research extensively searched the journal articles and some other I4.0 indexes used in some countries. Finally, the paper designed a comprehensive I4.0 index with determinant indicators comprising data life cycle (sources, collection, storage, analysis, and transmission) and smart product life cycles (designing, planning, monitoring, quality, and maintenance). This model is expected to be an essential contribution to improve INDI 4.0 in Indonesia. The I4.0 phenomena will undoubtedly influence all countries, and more research into this topic and other critical variables affecting I4.0 preparation are required to complete this study. To improve this research, additional research from other academics is needed to fill in the gaps, incompleteness, and loopholes.**

Keywords— **I4.0; INDI 4.0; readiness index; factory operation.**

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I. Introduction

Industry 4.0, famously referred to as the I4.0, was introduced in 2015 by Klaus Schwab, the Executive Chairman of the World Economic Forum in Davos-Switzerland [1], [2]. At first, I4.0 was originated in 2011 from the German government's high-tech strategy by emphasizing manufacturing computerization. This initiative determined three main components of I4.0, which are the Internet of Things (IoT), Cyber-Physical Systems (CPS), and Smart Factories [3]. After that, all governments worldwide, both developed and developing countries, have put the I4.0 on the national agenda to improve their global competitiveness and increase investment in respective countries.

Developed countries announced their national plan adopting I4.0 earlier than developing countries to support their national competitiveness. This action plan is an effort to secure a strong competitive position through technological innovation for enhancing productivity, efficiency, and competitiveness. German as an I4.0 initiative pioneer, announced a strategic initiative by issuing a high technology action plan in November 2011, securing a powerful competitive position through technological innovation [4].

China launched a particular action plan to boost integrating informatization and industrialization in August 2013 [5]. The project purposed to explore the integration of informatization and industrialization. It continued in 2015 by announcing the program Made in China in 2025 [6]. Currently, China affirms its country as a new industrial country, with global economic power catching up with developed countries.

The United States developed a framework for revitalizing American manufacturing in December 2009, then launched an advanced manufacturing partnership (AMP). This effort to ensure American leadership in the global manufacturing competitiveness [3], [7]. This similar action plan also occurred in other developed countries. They secured technology strength and a globally competitive position. I4.0 is a national strategic plan to boost industry capability and competitiveness through technology and innovation.

In Southeast Asian Nations, Singapore is the first rank in the policy launching timeline of I4.0 initiatives (see Figure 1) [8]. Bloomberg Innovation Index ranked Singapore as the fifth globally under the value-added manufacturing category in 2017, competing with the USA, Germany, and China [9]. Singapore is also the fourth largest exporter of high-tech goods globally, referring to the World Trade Organization in 2019 [9]. To reach ambition to be the global hub for the manufacturing, Singapore Smart Industry Readiness Index reflected industry maturity translating I4.0 concepts and technologies into new value. Singapore moved ahead of its neighbors in preparing the industry to adopt I4.0.

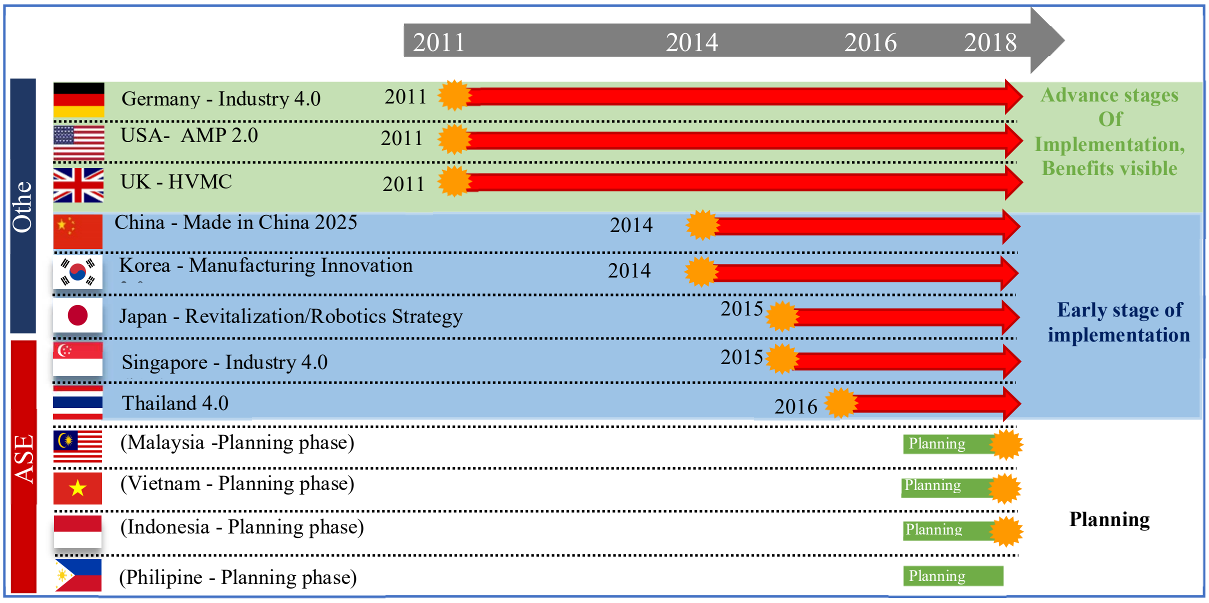

Fig. 1 Policy Launch Timeline of I4.0 Initiatives in ASEAN and Other Countries [8]

As a developing country, Indonesia seemly left behind to put the I4.0 as a national plan to improve competitiveness, as shown in Figure 1. Officially, Indonesia announced The Roadmap of Making Indonesia 4.0 in April 2018 to devote a considerable effort into catching up with other countries and putting the I4.0 as a national plan to improve competitiveness [10], [11]. Indonesia proposed a roadmap named Indonesia Making 4.0 by developing The I4.0 Readiness Index Indonesia (INDI 4.0) to measure the industry readiness to adopt I4.0 [10]. In preparing INDI 4.0, The Government of Indonesia involved academics, practitioners, industry professionals, researchers, experts, and leading global consultants, such as McKinsey and The Fraunhofer Institute. This model consists of five pillars as the primary measure for assessing the I4.0 readiness, as shown in Figure 2.

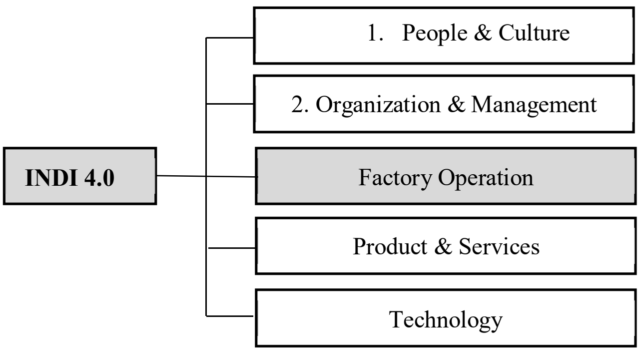

Fig. 2 The Five Pillars of INDI 4.0 [10]

Indonesia is a part of the initial planning phase group in Southeast Asia, with Malaysia, Vietnam, and the Philippines categorized in a low-rank position, even the lowest rank. Indonesia also spends less on information and communication technology (ICT) than its global peers [8]. Indonesia spends 1.3% of Gross Domestic Product (GDP), less than any country [8]. At least, it reflects the commitment and contribution towards I4.0 readiness. Investing in information, communication, and technology is a crucial element to boost adopting I4.0.

In 2018, government official report showed the I4.0 readiness, Indonesia's manufacturer obtained a low-level score with a total average of 1.992, scale from 0 to 4 [10]. This result reflected low maturity in the industry to adopt I4.0. To provide proper strategy in the roadmap towards I4.0, INDI 4.0 must provide accurate readiness level information in adopting I4.0, what gaps today, and where to start. The INDI 4.0 consists of 23 questions comprised 5 questions for people and culture, 5 for organization & management, 4 for factory operation, 4 for product and services, and 5 for technology, so a total of 23 questions.

This research focused on I4.0 readiness in factory operation by considering this area as the manufacturing industry's business core, a key element in the I4.0 concept, and one priority in Indonesia's I4.0 roadmap. INDI 4.0 provides very few questions to capture extensive information to measure I4.0 readiness. It lacks accuracy, is less comprehensive, and missing some significant points of I4.0 characteristics. These facts appear based on comparison to the existing I4.0 index used by other countries, some literature, feedback from some I4.0 focus group discussion, and interviews results from professionals, experts, and some team members in Indonesia Making 4.0, also an observation in a manufacturer which involved in INDI 4.0 project. This study aimed to develop a comprehensive I4.0 index by enhancing INDI 4.0 in the factory operation aspect and improving INDI 4.0 in Indonesia.

A. Industry 4.0

The term I4.0 appeared as a sign of entering the fourth industrial revolution. In history, the first industrial revolution occurred in the 18th century, changing traditional and simple technology into production mechanization, followed by the second industrial revolution with more intensified by advanced electrical and management entire 19th century. In the third industrial revolution around the 1970s, automation and information technology (IT) empowered the industry [12]. The I4.0 was first introduced in 2015 by Klaus Schwab, the Executive Chairman of the World Economic Forum in Davos-Switzerland.

Initially, I4.0 was originated in 2011 from the German high-tech strategy by emphasizing manufacturing computerization. This initiative determined three main components of I4.0, the Internet of Things (IoT), Cyber-Physical Systems (CPS), and Smart Factories [3]. The fourth industrial revolution is coming about information and communication technology, named I4.0. Germany initiated I4.0 as high technology leadership innovation and strategy in 2011.

The I4.0 is becoming a top issue for many researchers, universities, and companies that have defined I4.0 [13]. It is not a clear definition of what it means [14], [15]. The I4.0 Working Group's final report in Germany explained the vision, scenario, technologies, and I4.0 idea objectives but did not define I4.0 [13]. I4.0 as the new vision, by creating new models through CPS and featured nine pillars (big data, autonomous robots, simulation, additive manufacturing, IoT, cloud computing, augmented reality, horizontal and vertical integration cybersecurity [16].

Even though no consensus in the definition of I4.0, just providing benefit, vision, and technology. However, in principle, it consists of four design principles in implementing I4.0 [17]:

- Interconnection
- Information transparency
- Decentralized decisions
- Technical assistance

Interconnection reflects machines, devices, and sensors connected with wireless communication through the internet of things. The cyber-security concern is crucial when vital information flows in the network and the cloud. Information transparency creates interconnection of objects, and people quickly access all the information for the right people or objects, providing the virtual copy of the physical object. Decentralized decisions make the interconnection of things and people and more transparent in utilizing information from multi-source information. Technical assistance provides decision support systems to empower people to drive decision-making by transforming data into visualizing information. Technical assistance also provides physical assistance, such as advanced robotic technology, to support the factory floor's operations. I4.0.

The elements of technology in the I4.0 era [18] are as follows:

- Real-time capability and system integration
- Big data analytics, machine learning, and artificial intelligence
- Decision support system and automated decision making
- Vertical and horizontal system integration and cyber-physical system

I4.0 delivers the most relevant qualifying technologies, frequently cited in the literature, such as big data, the internet of things, cloud computing, autonomous robots, additive manufacturing, cyber-physical systems, and augmented reality [19]:

- Internet of Thing provides connectivity between sensors, machines, mobile and human devices, also decision is made based on data driven.
- Big data is a massive amount of data from various semi-structured, unstructured, and structured sources collected, filtered, stored, and connected through the IoT transformed into accurate and fast information in real-time for decision-making.
- Cloud is a computer system resource, mainly data storage and computing power, where data is stored with a quick response from the external environment through IoT.
- Cyber-Physical system integrates computation and physical processes, embedded computers and networks monitor and control the physical processes and transform technology for managing systems interconnected between physical and computational resources.
- An autonomous robot is a robot doing tasks supported by artificial intelligence (AI). Additive manufacturing is three-dimensional printing that produces small batches of custom products with an advantage, such as designing complex parts.
- Augmented reality allows interaction between humans and virtual objects simultaneously through a physical environment practically, as same as in the space of the real environment.

B. The Existing 14.0 Indexes

The Government of Indonesia designed INDI 4.0 by considering other prominent I4.0 indexes, involving experts, professionals, academics, and leading global consultants, such as McKinsey and The Fraunhofer Institute. Indonesia also did a benchmarking to other countries, which earlier planned a roadmap toward I4.0 readiness. The following are some of the I4.0 Indexes, which are well-known in literature and used in several countries.

1) Simmi 4.0: SIMMI 4.0 is System Integration Maturity Model I4.0. This model consists of four dimensions in measuring I4.0 readiness [20].

- Vertical integration (organizational/strategical aspects).
- Horizontal integration (Enterprise system).
- Digital Product Development (Digital production).
- Cross-sectional technology criteria (Cross-sectional technology).

Each dimension above in SIMMI 4.0 covers comprehensive process overall integration from suppliers to customers (horizontal) and from the field operation level to management top-level (vertical), including technology in that process. The I4.0 index readiness level, scoring by 1 to 5 with maturity level:

- Basic level.
- Digital level.
- Cross-departmental digitization level.
- Horizontal & vertical digitization level.
- Full digitization level.
- Optimized digitization level.

2) Dreamy: Dreamy is Digital Readiness Assessment Maturity Model. This model has similar to INDI 4.0, consisting of four pillars [21], [22]:

- Organization
- Process
- Technology
- monitoring & control

This model addresses the I4.0 Index by assessing digital process capability in:

- Design & Engineering
- Production Management
- Quality Management
- Maintenance Management
- Logistic Management
- Supply Chain Management

Dreamy divides I4.0 readiness level into six levels.

- Level 1: Computerization
- Level 2: Connectivity
- Level 3: Visibility
- Level 4: Transparency
- Level 5: Predictive Capacity
- Level 6: Adaptability
- Each level represents a score that is reflecting the I4.0 readiness level.

3) Acatech: Acatech is Akademie der Technikwissenschaften. This I4.0 Index is one of the initial model pioneers of the I4.0 index from Germany. There are four core elements of structural areas in the Acatech I4.0 Index.

- Organizational structure
- Technology
- Culture
- Information system

Acatech addresses the business process in functional areas such as development, production, logistics, services marketing-sales. The government initiated the Acatech I4.0 maturity Index to guide the organization to practice and develop Industry 4.0, and its implementation strategy aligned with business strategy [23]. This approach creates a digital roadmap for individuals, transforming themselves into learning and agile organizations that enable rapid decision-making and adaptation processes. There are six levels of maturity in Acatetech;

- Level 1: Computerization
- Level 2: Connectivity
- Level 3: Visibility
- Level 4: Transparency
- Level 5: Predictive Capacity
- Level 6: Adaptability
- Each level represents a score reflecting the I4.0 readiness level.

4) Rami 4.0: Germany has another I.4.0 index, namely Architectural Model for I4.0 (RAMI 4.0) developed by Platform Industry 4.0, one of the world's largest I4.0 networks [9], [24]. Platform I4.0 is an organization that officially launched at the Hanover Fair 2013. This organization is responsible for coordinating the transition into the digital economy in industry and science to keep Germany a leader in providing technologies and production. Crucial experts and respected associations have formally acknowledged this model as the reference architecture model that best embodies the key concepts and ethos of I4.0. RAMI 4.0 is the I4.0 index designed in service-oriented architecture by combining all elements and information technology and components in a layer and product life cycle model. RAMMI 4.0 introduced I4.0 as a transformation from Industry 3.0 with characteristics of hardware-based structure and functions, hierarchy-based communication, and isolated product [24]. RAMMI 4.0 embeds modern organization with I4.0 characteristics, which covers:

- Flexibility in systems and machines,
- Function distribution throughout networks,
- The participation of all hierarchy levels,
- Communication of all participants,
- The product is part of the network.

5) Singapore Smart Industry Index: Singapore developed Smart Industry Readiness Index. This model is a comprehensive tool for all companies, regardless of their size, for adopting I4.0. This tool provided an assessment approach covering three core elements of I4.0:

- Process
- Technology
- organization.

This model categorizing levels of readiness by scoring 1–5 for indexing I4.0 [9]:

- Level 0=undefined/none,
- Level 1=defined/basic/connected/computerized,
- Level 2=digital/advance/interoperable/visible,
- Level 3=integrated/full/secure/diagnostic,
- Level 4=automated/flexible/real-time/predictive,
- Level 5=intelligent/converged/scalable/adaptive)

Three core elements in this Singapore index are the same as the TUV Index because both are in the consulting partnership with the I4.0 project. The Singapore index is more detailed in sixteen dimensions as assessment areas that companies can use to evaluate their current readiness.

C. INDI 4.0 and Factory Operation Aspect

INDI 4.0 consists of five pillars to measure I4.0 readiness:

- The item measured management and organization consist of leadership and strategy, Investment for Adopting I4.0, and Innovation Policy.
- People and culture consist of competence development, culture, and openness to change.
- Product and services encompass services based on data, smart products, and product customization.
- The technology consists of cyber-security, connectivity, Smart machines, and Digitization.
- Factory operation includes data Storing & sharing, smart logistics, autonomy process, and smart maintenance

These five pillars comprise 23 questions with 5 questions for people and culture, 5 for organization & management, 4 for factory operation, 4 for product and services, and 5 for technology, so a total of 23 questions.

Factory operation is a crucial element in the I4.0 concept and one priority in the Indonesia roadmap. To measure I4.0 readiness in factory operation, INDI 4.0 captures information in a factory just addresses by four simple multiple-choice questions as below:

- Data storing & sharing
  In your company, where is company data stored?
  a. No data saved yet
  b. On each employee computer/hard disk
  c. On the servers of each department/section
  d. At the center of the company internal servers / corporate IT department
  e. In the cloud
- Smart logistic
  The following systems that have been implemented in your company supply chain and logistics are (can you choose more than one)?
  a. RFID products and components
  b. Barcodes on products and components
  c. GPS monitoring system
  d. Real-time inventory control
  e. Logistics integration between companies with vendors/suppliers
  f. Real-time product condition monitoring and components
  g. ERP
  h. AGV system
  i. Others
- Autonomy process
  In your opinion, what percentage of the automation process in your company?
  a. 0% b.25% c. 50% d. 75%. e. 100%
- Smart maintenance
  What has the company implemented systems in terms of machine maintenance systems?
  a. Real-time technology conditions
  b. Overall equipment effectiveness monitoring
  c. Predictive treatment
  d. Preventive maintenance
  e. Corrective care
  f. Not available

The study focuses on developing I4.0 Index in factory operation to enhance INDI 4.0. For example, logically and theoretically, capturing the I4.0 readiness of factory operation in data storing and sharing by asking where data is stored. It does not reflect I4.0 readiness in how data drives decision making as I4.0 characteristic in manufacturing [3], [9], [17], [25]. This study provides an I4.0 index more comprehensive and accurate by enhancing INDI 4.0 in the factory operation aspect.

II. Materials and Method

This paper designed a research structure by the method of scoping review. This approach comprises identifying existing articles, critically discussing the literature, identifying a loophole in INDI 4.0 as a research gap, reviewing the body of knowledge, and developing a new comprehensive I4.0 readiness index from a broad view of the underlying phenomenon in INDI 4.0 [26]. In this method, It facilitated the research structure establishing data collecting and analysis [26]. The scoping review consists of the five stages of the research process [25];

1) Identifying the research gap or loophole in INDI 4.0:

- Understand and deepen the I4.0 concept in INDI 4.0
- Preliminary observations by gathering facts and feedback from INDI 4.0 stakeholders, comparing to existing prominent I4.0 index, models used by other countries, focus discussion group feedback, and interview result from professionals, experts, and some team members in Indonesia Making 4.0
- Reviewing, observing, interviewing INDI 4.0 projects in several manufacturing industries which involved in program Making Indonesia 4.0
- Identifying loophole and missing points in INDI 4.0

2) Identifying relevant studies (I4.0 concept, Simmi 4.0, Dreamy, RAMI 4.0. Acatech, and Singapore Industry Smart Index).

3) Studying and selecting the best approach:

- Comparing INDI 4.0 to other I4.0 indexes
- Analyzing loophole and selecting best indicators I4.0 readiness
- Drafting scope of I4.0 indicators to enhance INDI 4.0 effectiveness
- Delivering new draft to FGD, some stakeholders of I4.0 project, and experts

4) Collating, summarizing, and reporting the results.

III. Result and Discussion

This study compared INDI 4.0 to I4.0 indexes used in other countries by sequencing how the I4.0 index developed from beginning until application on industry readiness assessment. The following description is some approaches and analysis as a result and discussion.

A. Comparing the steps creating the I4.0 readiness index

From observing documents of the I4.0 index from some countries and some literature reviewed, most countries seem to use the same playbook to develop the I4.0 readiness index. They seem to have similar patterns in establishing objectives, defining the I4.0 roadmap. The steps in creating I4.0 readiness index also have similar pattern, such as; [3], [8]–[10], [23], [24], [27].

- Research and evaluation
- Designing and developing the I4.0 readiness index
- Validating Index with industry and stakeholders (academics, experts, and key associations)
- Creating a pilot project
- Ensuring successful pilot projects
- Publication

There are no irregularities and differences in principle in steps and how to create the INDI 4.0 and I4.0 index in other countries.

B. Comparing dimension of major I4.0 indexes

The differences of dimension in the respective of I4.0 index above do not mean reflecting absolute difference. It could only be a difference in terms but with the same purpose, meaning, and substance. For example, it implicitly reflects the same meaning in terms of process and factory operation, technology, digital development, information system, management and strategy, people, culture, organization, etc. (see Table 1).

On the other hand, even though an I4.0 index does not mention a particular dimension, it is explicitly said in detailed questions. For example, the Singapore smart industry index does not mention vertical and horizontal integration, but in the breakdown of dimension into detail question, vertical and horizontal clearly and explicitly mentioned. The dimensions of INDI 4.0 have no significant difference with other indexes because it consists of standard dimensions covered by other indexes adjusted to each country's circumstances.

TABLE I
COMPARISON OF I4.0 INDEX DIMENSIONS

Dimensions	I4.0 Indexes						
	1	2	3	4	5	6	7
Organization	X	X	X	X		X	X
Technology	X	X	X	X	X	X	X
Information system							X
Process	X	X	X	X		X	
Management							
Factory operation	X	X				X	
Product & services	X				X		
Strategy	X						
Resources							
Vertical Integration		X		X	X	X	
People	X						
Communication				X			
Digital Development					X		
Horizontal integration		X		X	X	X	
Product Lifecycle				X			
Culture	X						X
Monitoring and control			X				

Note 1). INDI 4.0 2). Singapore Smart Indexes 3). Dreamy 4). Rami 4.0 5). Simmi 4.0 6). TUV 7). Acatech

C. *Comparing the INDI 4.0 question instrument in detailed dimension*

In detailing the INDI 4.0 instrument by breaking down dimensions into the questionnaire, it lacks comprehensive approaches compared to the others. For example, capturing the I4.0 readiness of factory operation covered only four simple multiple-choice questionnaires.

- Where is data stored?
- What system is implemented in the supply chain?
- What percentage of automation process?
- What system is implemented in machine maintenance?

The question above is a loophole in INDI 4.0. It represents I4.0 readiness dubiously fulfills the objectives. Some issues need a review for these four-question instruments. The four questions from INDI 4.0 are too few and specific for accurately capturing I4.0 readiness in factory operations. Question No.1, where data is stored, is too narrow and does not represent I4.0 readiness. Data-driven manufacturing is a key element in I4.0. It is not only where data stored [3], [9], [23], [28], [29]. Data storage is one of the stages in the data life-cycle, conveying and flowing data effectively from a data source, then collected, stored, processed, transformed into information, transmitted, visualized, and applied for decision making as one of I4.0 characteristics [6], [13], [30], [31].

In question No.2, what system is implemented in the supply chain? This question provides multiple-choice answers that can pick more than one option, such as RFID, barcodes on products and components, GPS, real-time inventory, so on. It could reflect I4.0 readiness, but partially only capturing a few technology or system in I4.0 elements and not covering technology in a comprehensive vertical & horizontal integration and product life-cycle like other indexes [9], [22], [27], [32], [33]. This question purposed to capture information in a broad object of the supply chain from a system and technology perspective, like catching a large number of fish with a fishing rod.

Question No. 3, what percentage of the automation process, It is no clear guidance on how a manufacturer assesses automation percentage level and proportion in process. It is unclear whether the automation process means the machines, devices, computers, safety, communication, particular area, and how to calculate percentage and proportion of automation process. This study has not found any I4.0 index in calculating automation process percentage.

Question No. 4 what system is implemented in terms of machine maintenance systems? This question provides multiple-choice answers that can pick more than one option, such as real-time technology conditions, overall equipment Effectiveness monitoring, predictive treatment, preventive maintenance, corrective care, and so on. Adopting I4.0 is not only about what technology and system are applied or how sophisticated it is. This question just captures very few technology elements of I4.0 that consist of system integration, automated decision-making, machine learning, communication, and information technology integration, vertical and horizontal process integration, big data analytics, and artificial intelligence [3], [4], [9], [13], [16]–[18]

D. *INDI 4.0 and I4.0 Characteristics*

INDI 4.0 questionnaire lacks covering I4.0 characteristics such as design principles of I4.0 [13], [15], [17], technology elements [27], and three features of I4.0, such as internet of things, cyber-physical system, and smart manufacturing. INDI 4.0 does not mention interconnection, information transparency, decentralized decisions, and technical assistance as four elements of the design principle of I4.0 that proposed many pieces of literature in any questions of factory operation. Even though the official roadmap and plan explicitly explained design implementation and technology elements in I4.0, it was not addressed on the questionnaire.

INDI 4.0 is less comprehensive than other indexes, like the Singapore Smart Industry Index has 16 dimensions in assessing I4.0 readiness. For example, a dimension uses a question in assessing I4.0 readiness on process or factory operation:

> *Vertical integration integrates processes and systems across all hierarchical levels of the automation pyramid within a facility to establish a connected, end-to-end data thread.*

This question is complete capturing I4.0 features, explore information about design principle implementing and technology elements of I4.0. Each question in the Singapore smart industry index clearly defines, describes, and details how to rank the Index or levels, from low level (undefined) to intelligence level. A clear definition and description accompany every level.

Of course, INDI 4.0 and other indexes do not have to be the same in the I4.0 index assessment approach. Each of them has different industrial characteristics and conditions. The current instrument is more effective if developed in more detail to guide a single manufacturer in implementing I4.0. This approach makes it easier for the industry to do self-assessment at what level in I4.0 readiness

INDI 4.0 helps the government overview, map out the policy to adopt I4.0, and get the big picture in general of I4.0 readiness. In contrast, it does not guide the industry clearly to get a complete picture of the current gap and where to start adopting I4.0. INDI 4.0 must be effective to measure accurately I4.0 readiness as guidance for industry in adopting I4.0. This study is trying it.

E. Developing New platform of Comprehensive I4.0 index

This study developed a platform for the I4.0 readiness index. This platform is a foundation to design instruments to measure I4.0 readiness. There are five standpoints as the basis of this platform:

- Data
- Smart Product life cycle
- Horizontal and vertical integration
- Design principle of I4.0
- I4.0 Technology elements

These four standpoints are crucial factors always mentioned in any literature and I4.0 indexes.

1) Data: Data is an essential element of I4.0 characteristics, mentioned as an indicator in all I4.0 indexes [9], [10], [22], [27], [32], [33], even before I4.0 age, data play a significant role in any production stage [34]. The transformation of conventional manufacturing into a smart factory where data-driven manufacturing is an essential part of the I4.0 [35]. The smart factory aims to transform data acquired across the multi-source into manufacturing intelligence to impact manufacturing aspects positively [28]. Data in factory operation regarding complete data journey in manufacturing operation [6], [30] are as follows:

- Data source
- Data collection
- Data transmission
- Data storage
- Data processing
- Data application

Data aspects are about storage, like a question in INDI 4.0, but data flow in the data life cycle.

This data flow sequence can be referred to as the "data life-cycle" [6], [30]. Data is also the primary key involved with the technologies of I4.0 based on the extant literature in Table 2 that indicates most frequently cited from pieces of literature paper by Pacchini *et al.* [27]. In Table 2, Big data and cloud are the most frequently cited technology from literature with the most significant number (both total 28 cited), both related to the data as the central key role.

TABLE II
THE BIG FIVE TECHNOLOGIES KEYS OF I4.0 BASED ON THE EXTANT LITERATURE [27]

No	Paper/Author	Ref.	1	2	3	4	5
1	Zhong et al. (2017)	[36]	X	X	X	X	
2	Xu et al. (2018)	[37]	X		X	X	
3	Vaidya et al. (2018)	[38]	X	X	X		X
4	Schmidt et al. (2015)	[39]	X	X	X	X	
5	Santos et al. (2017)	[40]	X	X	X	X	X
6	Roblek et al. (2016)	[41]	X	X	X	X	
7	Posada et al. (2015)	[42]	X	X			X
8	Pereira and Romero (2017)	[43]	X	X	X	X	
9	Lu (2017)	[44]	X	X	X	X	
10	Liu and Xu (2017)	[29]	X	X	X	X	X
11	Guoping et al. (2017)	[45]	X	X	X		X
12	Dombrowski et al. (2017)	[46]	X	X	X	X	
13	Chhetri et al. (2017)	[47]	X	X	X	X	X
14	Caiazzo (2018)	[48]	X		X		X
15	Bortolini et al. (2017)	[49]	X	X	X	X	X
16	Ahuett-Garza and Kurfess (2018)	[12]	X	X		X	X
	TOTAL		16	14	14	12	9

Note: 1) Internet of Thing 2) Big data 3) Cloud 4) Cyber Physical-system 5) Additive Manufacturing

2) Smart Product life cycle: The product life cycle is the journey of developing and delivering a product and ending up disappearing in the market. It consists of the amount of time the product goes from the beginning to the market until it is taken off the shelves because it is no longer sold. Product life-cycle is the main part in major I4.0 indexes like Rami 4.0 [24], [36], and Singapore smart industry index [9], also definitely as part of dimensions in other I4.0 indexes. Tao characterized the product life-cycle in data-driven manufacturing as an essential part of I4.0 consist of smart design, smart planning, smart monitoring, smart maintenance, smart quality, and smart logistic [6].

In measuring the I4.0 readiness of the manufacturing industry, it is impossible to get accurate information when assessment is just addressed to the single process partially. Measuring shall be carried out to the whole journey of the product life cycle.

3) Vertical and Horizontal integration: Vertical and horizontal integration always be part of the I4.0 index in all models used in any country. Most literature put the process integration as a major indicator in I4.0 (see Table 1). Vertical integration integrates processes and systems across all hierarchical levels of the automation pyramid within a facility to establish a connected, end-to-end data thread from field level to business level. Horizontal integration is the integration of enterprise processes across the organization and with stakeholders along the value chain. It integrates enterprise processes across the organization and with stakeholders along the value chain. Vertical and horizontal integration in this platform is represented where data flows in vertical integration from field level, operational, process control, plant management until business level or top management. It flows from sources in raw data, collected, stored, processed, and transformed into information. It reflects the data life-cycle journey through vertical and horizontal integration.

4) Design Principle of I4.0: Mario Herman, Tobias Pentek, and Boris Otto from Dortmund University initially proposed the design principles of I4.0. This idea is most frequently cited in many papers and I4.0 international conference. The design principles of I4.0 consist of interconnection, information transparency, decentralized decisions, and technical assistance [13] [17]. In this platform, the design principles of I4.0 identify and offer comprehensive information on how the industry selects guidance during implementation [13]. That is why it is used in this study.

5) Technology elements of I4.0: Table 2 showed the technology elements of I4.0 based on papers and major I4.0 indexes. This table just showed the big five most frequently by paper in 2019. Of course, there are many other types of technology that characterize Industry 4.0. Table 2 lists only the top five that are most cited. The technology refers to I4.0 characteristics covering real-time capability, system integration, big data analytics, machine learning, artificial intelligence, decision support system, automated decision making, vertical and horizontal system integration, and cyber-physical system [18]. Technology is a significant parameter in measuring I4.0 readiness in any model and is definitely included in this platform.

From the platform of new I4.0 readiness in factory operation, this study interpreted the four standpoints into a questions instrument as shown in Figure 3 below. This platform was proposed to review, compare, and analyze literature and I4.0 indexes used by other countries like Singapore and Germany. This study also carried out focus group discussions involving academics, some team members involved in the I4.0 project in Indonesia, and some practitioners from Denso, Toyota, Mitsubishi, and some prominent manufacturing industries. Here is Figure 3 showed the flat form of the I4.0 readiness index of factory operation.

F. Developing instrument of I4.0 readiness index

From Figure 3, this study developed the questions instrument to measure I4.0 readiness. This instrument is applied into four methods: survey, interview, observation, and verification. Figure 3 showed the data life cycle, and the product life cycle reflected vertical and horizontal integration. The data life cycle is broken down into 6 questions, and the product life cycle into 11 questions, a total of 17 questions. These questions could be submitted by survey method with multiple-choice answers. Each answer option represents I4.0 readiness:

1. ML 1 (Maturity Level 1) = Initial - Poorly controlled processes, reactive management, lack of technical tools
2. ML 2 (Maturity Level 2) = Defined - Planned controlled process, partially preventive process management, using technical tools
3. ML 3 (Maturity Level 3) = Integrated & interoperable – Fully planned controlled & integrated process, partially predictive process management, advanced technical tools & technology in best practices.
4. ML 4 (Maturity Level 4) = Digital oriented – Digital oriented process, predictive process management for high potential growth, data and information are fast, robust, and secure.

The questions represent data life cycle and smart product life cycle.

1. Data source - In your factory operation, where do data sources mostly come from?
2. Data collection - How is the data in your organization?
3. Data stored - Where is the data in your organization stored?
4. Data analysis - What technology to analyze data in your organization?
5. Data analysis - What statistical tools are applied in your organization?
6. Data transmission - What technology is used in data transmission?
7. Design - What data sources in designing a product in your organization?
8. Design - How is data collected in designing a product?
9. Design - What technology is used to design a product, especially in transforming data into a design prototype?
10. Planning - How does your organization utilize technology in production planning?
11. Maintenance - What maintenance system is implemented in your organization.
12. Monitoring - What scopes of the manufacturing process can your organization monitor?
13. Monitoring - How does technology monitor the manufacturing process?
14. Monitoring - How does your organization carry out a distribution & tracking system?
15. Monitoring - What technology supports distribution & tracking in your organization?
16. Quality - How is data collected purposed to quality objective achievement?
17. Quality - What statistical tools are used in quality control (QC) and quality assurance (QA)?

The questionnaire above just captures I4.0 readiness in the factory operation aspect. Each answer represents the option that reflects the level I4.0 readiness (ML 1, ML 2, ML 3, ML 4). For example, question No.3 above.

Data Stored - Where is the data in your organization stored?

☐ Individual computer
☐ Databases in department server
☐ Central server
☐ Cloud

The answer reflects what level of I4.0 readiness.

Figure 3 showed design principles and technology elements of I4.0 as part of a platform of I4.0 readiness to support data & product life cycle questions. The I4.0 design principles are broken down into 5 questions, and technology elements into 6 questions, 11 questions. This approach used open questions, not multiple-choice. Interviews and observation deliver this model question to support and confirmed previous information from the survey (data & product life cycle).

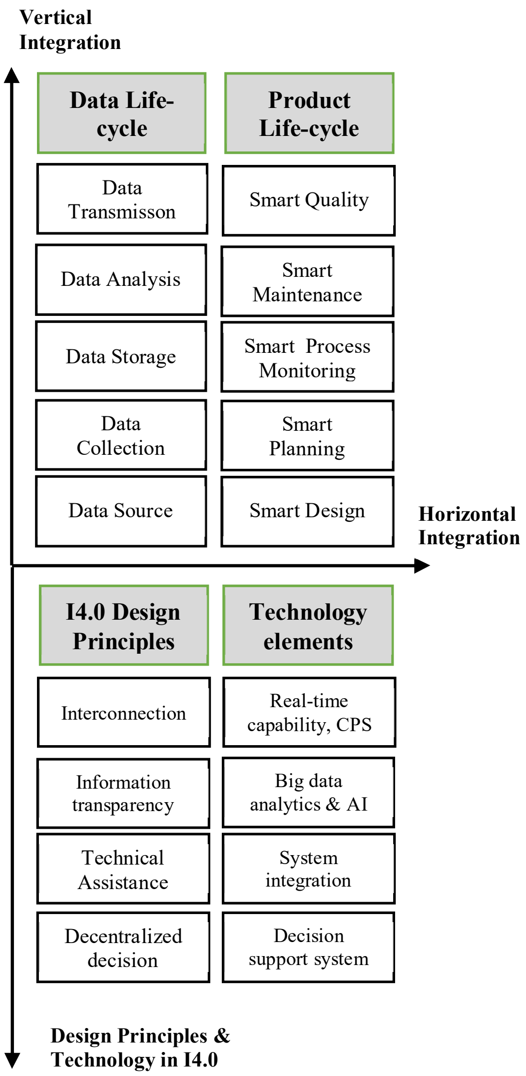

Fig. 3 The Platform of I4.0 readiness index in factory operation aspects

This study recommends open questions representing design principles and technology elements of I4.0 as an additional qualitative approach by interviewing and observing to support, confirm, and deepen required information to complete the survey. The interview was purposed to capture what miss in the self-assessment survey or to complete and verify the survey result. Observation is subject to verify information and data from interviews and self-assessment.

The questions represent design principles and technology elements of I4.0.

Design principles of I4.0

1. Interconnection [17] - How does your company use wireless communication technologies, making interconnection three types of collaboration within the internet of things; human-human, human-machine, and machine-machine [35].
2. Decentralized decisions [17] – How to make decentralized decisions based on the interconnection of objects, people, and transparency of information.
3. Technical assistance [17] - How does your company provide virtual assistance in the organization, such as systems, can aggregate and visualize information comprehensibly, ensuring that humans can make informed decisions and solve urgent problems on short notice[37]
4. Technical assistance [17] - How does your company provide physical assistance for more effective and safe human support in physical tasks[38].
5. Information transparency [17] - How does your company create information transparency by applying data analytics to analyze it and transforming it into crucial information [37].

Technology elements of I4.0

1. Real-time capability and system integration - How do data of life-cycle flow in all production processes empower decisions at the right time and as early as possible.
2. Real-time capability and system integration - How is the abnormality in production detected?
3. Big data analytics, machine learning, and artificial intelligence - What data technology is used and how it supports transforming data into crucial information
4. Decision support system and automated decision making - How does your company perform decision support systems, whether fully computerized or human-powered or a combination of both
5. Vertical and horizontal system integration - How to integrate a system and physical processes across all hierarchical levels in factory operation and supply (field, operation control, planning, and business level)
6. Vertical and horizontal system integration - The technology can integrate systems and machines, sensor devices, and human resources through IoT and IoP, then IoE.

IV. Conclusion

In capturing the I4.0 readiness of factory operation, INDI 4.0 dubiously fulfills their objectives. The question instrument is too narrow. It did not cover the I4.0 features & principles such as data-driven manufacturing, smart factory, design principles, and technology elements of I4.0. The gap in INDIA 4.0 caused the Index's impact to lack comprehensive, less accurate, and missing important points from the I4.0 characteristic. The paper contributes to the ongoing discussion centered around the I4.0 readiness index for academics and practitioners, especially in the factory operation aspect in developing countries like Indonesia. By providing a new I4.0 readiness index of factory operation, this paper creates a comprehensive model to measure I4.0 readiness based on I4.0 principles and characteristics. Furthermore, this model supports academics in identifying, describing, and selecting indicators of I4.0 readiness in the context of further investigations. Limitations of the paper are the scope of I4.0 readiness and research method. As the focus of I4.0 readiness on factory operation in INDI 4.0, relevant contributions in other aspects, other models, and countries might be left unnoticed. Researchers and practitioners are welcome to investigate further, revise, and improve the accuracy and usefulness of this I4.0 readiness. The I4.0 phenomenon is coming inevitably to any countries, and this issue needs more explored to complete this research and other vital dimensions affecting I4.0 readiness. This research requires more exploration from other researchers to complete deficiency, incompleteness, and loophole to make this research better.

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