DEVELOPING AN INSTRUMENT TO MEASURE INDUSTRY 4.0 READINESS FOR MANUFACTURING OPERATIONS IN INDONESIA

HASBULLAH

A thesis submitted in fulfillment of the requirement for the award of the Doctor of Philosophy of Mechanical Engineering

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This thesis is dedicated to

For my beloved mother HAJJAH AFIFAH BINTI ABDURRAHIM,

my father HAJI HASANUDIN BIN ALMAIDI, my dear wife LIA ASTRININGSIH,

my beloved kids RAISSA OZORA HASBULLAH, JAFIS QUBBA HASBULLAH,

QUEEN D'AFIFAH HASBULLAH, and GIBRAL THARIQUE HASBULLAH

To my beloved supervisor,

PROF. MADYA DR. SH SALLEH BIN SH AHMAD

for your guidance, your opinions and the knowledge you shared

will always be remembered in the future.

To my beloved friends and housemates

Your advice and your care will always

be appreciated and remembered

Thank you

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In the name of Allah, The Most Gracious and The Most Merciful

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ABSTRACT

Indonesia has low Industry 4.0 (I4.0) readiness in ASEAN and has the INDI 4.0 (Indonesia I4.0 Readiness Index) instrument, which is less comprehensive and accurate. An initial survey confirmed that only 56.86% of respondents agreed that the INDI 4.0 instrument accurately measures readiness in the manufacturing industry. Compared to the existing primary I4.0 instruments, the INDI 4.0 lacks of comprehensive I4.0 dimensions and characteristics. The main objective of this study is to develop an instrument to measure I4.0 readiness to enhance I4.0 in Indonesia through an exploratory mixed-method research approach with a multiphase research design. To achieve this objective, the initial observation in this study identified the dimensions and indicators representing I4.0 readiness through literature and document review by comparing them to the INDI 4.0 instrument, then confirmed them with an exploration survey. Phase 1 consists of a qualitative approach through interviews and observations to explore dimensions and indicators that represent I4.0 readiness. This phase successfully identified seven dimensions: Technology, Data-life cycle, Smart maintenance, I4.0 Design principle, People, Smart factory, and Management. These seven dimensions are broken down into 49 indicators of I4.0 readiness. Phase 2, through a quantitative approach by evaluation survey, confirmed 47 of 49 indicators from Phase 1. Finally, this study developed an instrument consisting of seven dimensions and 47 indicators to measure I4.0 readiness from level 0 to 4 that reflects readiness level (0=not ready, 1=early readiness stage, 2=moderate readiness, 3=full readiness. 4= already implemented). The improvement offered in this study on the existing instrument for measuring I4.0 readiness is more comprehensive by consolidating current instruments from the literature review, some other overseas country standards, and significant feedback from industries struggling to adopt I4.0 in a developing country such as Indonesia.

ABSTRAK

Indonesia berada di tahap kesediaan Industri 4.0 (I4.0) yang rendah di ASEAN dan mempunyai instrumen INDI 4.0 (Indeks Kesediaan Industri 4.0 Indonesia) yang kurang komprehensif dan tepat. Tinjauan awal mengesahkan, hanya 56.86% responden bersetuju bahawa instrumen INDI I4.0 berupaya mengukur dengan tepat kesediaan dalam industri pembuatan. Berbanding dengan instrumen I4.0 utama sedia ada yang lain, INDI 4.0 tidak meliputi dimensi dan ciri I4.0 secara komprehensif. Kajian ini bertujuan untuk membangunkan instrumen bagi mengukur kesediaan I4.0 dalam usaha untuk meningkatkan I4.0 di Indonesia, melalui pendekatan penyelidikan kaedah campuran penerokaan dengan reka bentuk penyelidikan berbilang fasa. Untuk mencapai objektif ini, pemerhatian awal dalam kajian ini mengenal pasti dimensi dan indikator yang mewakili kesediaan I4.0 melalui kajian literatur dan dokumen, membandingkan dengan instrumen INDI 4.0, kemudian mengesahkannya dengan tinjauan penerokaan. Fasa 1 terdiri daripada pendekatan kualitatif melalui kaedah temu bual, dan pemerhatian untuk meneroka dimensi dan penunjuk yang mewakili kesediaan I4.0. Fasa ini berjaya mengenal pasti tujuh dimensi: Teknologi, Kitaran hayat data, Penyelenggaraan pintar, Prinsip reka rentuk I4.0, Sumber manusia, Perkilangan pintar dan Pengurusan. Tujuh dimensi ini dikelaskan kepada 49 penunjuk kesediaan I4.0. Fasa 2, melalui pendekatan kuantitatif, melalui tinjauan penilaian, mengesahkan 47 daripada 49 penunjuk daripada Fasa 1. Akhir sekali, kajian ini membangunkan instrumen yang terdiri daripada tujuh dimensi dan 47 indikator untuk mengukur kesediaan I4.0 dari tahap 0 hingga 4 yang menggambarkan tahap kesediaan (0=tidak bersedia, 1=peringkat kesediaan awal, 2=kesediaan sederhana, 3=kesediaan penuh. 4= sudah dilaksanakan). Penambahbaikan yang ditawarkan dalam kajian ini terhadap instrumen sedia ada dalam mengukur kesediaan I4.0 adalah lebih menyeluruh dengan menyatukan instrumen semasa daripada kajian literatur, beberapa piawaian negara luar yang lain, dan maklum balas penting daripada industri yang bergelut untuk mengadaptasi I4.0 di negara membangun seperti Indonesia.

CONTENTS

DECLARATION **iii**

DEDICATION **ivv**

ACKNOWLEDGEMENT **v**

ABSTRACT **vii**

ABSTRAK **viii**

CONTENTS **viii**

LIST OF TABLES **xii**

LIST OF FIGURES **xiv**

LIST OF SYMBOLS AND ABBREVIATIONS **xvi**

LIST OF APPENDICES **xviii**

CHAPTER 1 INTRODUCTION **1**

1.1 Background of Study 1

1.2 Problem Statement 15

1.3 Objectives 19

1.4 Scopes 19

1.5 Thesis Organization 22

CHAPTER 2 LITERATURE REVIEW **24**

2.1 Introduction 24

2.2 Industry 4.0 24

2.3 I4.0 Dimensions and Characteristics 28

2.3.1 Smart Factory In I4.0 30

2.3.2 Data Life-cycle 34

2.3.3 Technologies in I4.0 37

2.2.4 Design Principles of Industry I4.0 44

2.4 The I4.0 Initiatives in Some Countries 47

2.4.1 Germany 48

2.4.2 The USA 49

2.4.3 China 49

	2.4.4	Singapore	50
	2.4.5	Malaysia	59
	2.4.6	Indonesia	63
2.5	Existing Main I4.0 Readiness Instruments		68
	2.5.1	SIMMI 4.0	69
	2.5.2	DREAMY	71
	2.5.3	Acatech	73
	2.5.4	RAMI 4.0	76
	2.5.5	IMPULS	78
2.6	Research Gap		81
2.7	Conclusion of The Chapter		89
CHAPTER 3 METHODOLOGY			**90**
3.1	Introduction		90
3.2	Research design		91
	3.2.1	Mixed-Method Definition	91
	3.2.2	Reasons For Using Mixed-Method Research	92
	3.2.3	Philosophical Foundations of Mixed Method	93
	3.2.4	Positivism	93
	3.2.5	Interpretivism	94
	3.2.6	Post-Positivism	94
3.3	Research Procedure		98
	3.3.1	Pre-research	100
	3.3.2	Phase 1 of Research	102
	3.3.3	Phase 2 of Research	102
	3.4.2	Data analysis	103
	3.3.5	Instrument Final Validation	104
3.4	Research method		104
3.5	Conclusion of The Chapter		108
CHAPTER 4 DATA COLLECTION AND RESULTS			**109**
4.1	Pre-Research		109
	4.1.1	Introduction of Pre-Research	109
	4.1.2	Data Collection in Pre-Research	110
	4.1.3	Result of Exploratory Survey	120
	4.1.4	Conclusion of Pre-research	125

4.2 Interviews 125

4.2.1 Introduction of Interviews 125

4.2.2 Data Collection In Interviews 126

4.2.2.1 Mechanism of Interviews 126

4.2.2.2 The Profile of Respondents 127

4.2.2.3 Designing Questions 134

4.2.2.4 Planning of Interviews 136

4.2.3 Result of Interviews 137

4.2.4 Categorizing Findings Related to I4.0 Indicators 157

4.2.5 Conclusion of Interviews 166

4.3 Evaluation Survey 166

4.3.1 Introduction of Evaluation Survey 166

4.3.2 Data Collection in Evaluation Survey 167

4.3.2.1 Evaluation Survey Preparation 167

4.3.2.2 Respondent Profile 168

4.3.3 Result of Evaluation Survey 171

4.4 Conclusion of The Chapter 176

CHAPTER 5 DISCUSSION 178

5.1 Introduction 178

5.2 Pre-research findings 178

5.2.1 Literature & Documents Review 178

5.2.2 Stakeholders Review 181

5.2.3 Exploratory Survey 183

5.3 Qualitative findings 183

5.4 Quantitative findings 187

5.4.1 Cluster Analysis of Evaluation Survey 188

5.4.2 Cluster Analysis of Exploration Survey 194

5.5 Discussion 200

5.5.1 The Indonesia I4.0 Instrument Review 203

5.5.2 Instrument To Measure I4.0 Readiness 207

5.5.3 Other Important Findings 210

5.5.4 Final Validation of Instrument 214

5.6 Limitation 214

5.7 Contribution 216

5.8 Impacts 217

CHAPTER 6 CONCLUSION AND RECOMMENDATION 219

6.1 Conclusions 219

6.2 Recommendations 222

REFERENCES 224

LIST OF TABLES

1.1 The Ranking of Countries in Readiness to Use Frontier Technologies 4
1.2 UNCTAD Innovation and Technology Report 2023 4
1.3 Global Index of Digital Entrepreneurship Systems (GIDES) 2022 5
1.4 Digital Transformation Index, UN-ESCAPE Report 2022 6
2.1 Enabling Technologies in the I4.0 37
2.2 The keys of technology in The I4.0 based on the literature 38
2.3 The Dimension of Vertical Integration in Operation Dimension 58
2.4 Overview of the Questionnaire to Apply SIMMI 4.0 70
2.5 Dimensions of Prominent I4.0 Readiness Instrument 82
2.6 Weakness and Strength of Exiting I4.0 Instrument 83
3.1 Summary of research objectives, questions, and types of collected data 96
4.1 The Participants Involved in Exploration Survey Instrument 111
4.2 Response distribution by respondent's opinion about I4.0 120
4.3 Level of Importance in Terms of Conformity I4.0 Indicators to I4.0 122
4.4 List of I4.0 Indicators That Have a Very Important 124
4.5 Classification of respondents in Interview Part 1, 2, 3 128
4.6 Respondent's Profile of Interviews 131
4.7 Questions of Interview Part 1, 2 & 3 147
4.8 Dimensions and Indicators of I4.0 Based on Interviews 162
4.9 Distribution of Respondent's Response to Statement Related to I4.0 171
4.10 Result of Evaluation Survey 172
5.1 Dimensions and Indicators of I4.0 Based on Literature Review 182
5.2 Indicators of I4.0 from interviews Grouped Based on Literature Review 185
5.3 Level of Importance of Each Indicator in I4.0 in Evaluation Survey 189
5.4 Descriptive Statistical Results of Evaluation Survey 191
5.5 Final Cluster Centers 192
5.6 Number of Cases In Each Cluster 193
5.7 ANOVA for Cluster Analysis 193
5.8 Level of Importance of Variable I4.0 in Exploratory Survey 195

5.9 Descriptive Statistical Results of Exploration Survey 197
5.10 Final Cluster Centers 198
5.11 Number of Cases In Each Cluster 199
5.12 ANOVA for Cluster Analysis 200
5.13 Instrument to measure I4.0 Readiness 207
5.14 Framework of the roadmap toward I4.0 211

LIST OF FIGURES

1.1	Policy Launch Timeline of I4.0 Initiatives in ASEAN & Others	2
1.2	The Five Pillars of the Indonesia I4.0 Readiness Instrument	7
1.3	The Initial Results of the Assessment Using Indonesia I4.0 Instrument	8
1.4	Number of Companies Assessed I4.0 Readiness in Indonesia	8
1.5	Number of INDI 4.0 Certified Companies Score $\geq$ 3.40	9
1.6	The Dimensions of Factory Operation in Indonesia I4.0 Instrument	16
1.7	Research Scope of Research	20
2.1	Four design principles of I4.0	27
2.2	The Automation Pyramid	34
2.3	The Framework of the Singapore Smart Industry Instrument	52
2.4	Platform of Industry 4WRD in Malaysia	61
2.5	Structure of 4FWRD Readiness Assessment	62
2.6	Five Manufacturing Sector Priorities in the Roadmap of I4.0	66
2.7	Structure of RAMI 4.0	76
2.8	Framework of IMPULS I4.0 Readiness	79
3.1	Research Procedure	99
3.2	Data Collection Method	105
4.1	The Respondent's profile distribution by Industry field	118
4.2	The Respondent's profile distribution by experiences	118
4.3	The Respondent's profile distribution by business field	119
4.4	The Respondent's profile distribution by respondent's position	119
4.5	Response distribution by respondent's management level	119
4.6	Creating Nodes in NVivo	137
4.7	The Digital Transformation Roadmap (Source RSP 03)	148
4.8	Digital Transformation Roadmap from Document (Source RSP 03)	149
4.9	Digital Transformation Roadmap (Source: RSP 05)	150
4.10	Keypoints of Technolgy	158
4.11	Keypoints of Data lif-cycle	158
4.12	Keypoints of Smart Maintenance	159

4.13	Design Principles of I4.0	159
4.14	Keypoints of People	160
4.15	Keypoints of Smart factory	160
4.16	Keypoints of Management	161
4.17	Distribution of Respondent's industrial sectors	169
4.18	Distribution of Respondent's organization/business fields	169
4.19	Distribution of Respondent's Position or Profession	170
4.20	Distribution of Respondent's Experience	170
5.1	The Platform of I4.0 readiness lead indicators in factory operation	206

LIST OF SYMBOLS AND ABBREVIATIONS

ACATECH	=	Akademie der Technikwissenschaften–Deutsche / German Academy of Science and Engineering
AGV	=	Automated Guided Vehicles
AI	=	Artificial Intelligence
AMP	=	Advanced Manufacturing Partnership
AR	=	Augmented Reality
ASEAN	=	Association of Southeast Asian Nations
CEPSI	=	Conference of the Electricity Power Supply Industry
CPS	=	Cyber Physical-System
CMMI	=	Capability Maturity Model Integration
DREAMY	=	Digital Readiness Assessment Maturity Model
EFFRA	=	European Factories of the Future Research Association
ERP	=	Enterprise Resources Planning
FGD	=	Focus Group Discussions
GPS	=	Global Positioning Systems
HMI	=	Human Machine Interface
IEC	=	International Electrotechnical Commission
ISIEM	=	International Seminars on Industrial Engineering and Management
FGD	=	Focus Group Discussion
I4.0	=	Industry 4.0
ICT	=	Information Communication Technology
ICRET	=	International Conference on Renewable Energy Technologies
IDC	=	International Data Corporation
IFERP	=	Institute For Engineering Research and Publication
I4.0	=	I4.0
IMPULS	=	I4.0 Instrument From Impuls Foundation, Germany
INDI 4.0	=	Indonesia I4.0 Readiness Index
IoT	=	Internet of Things

IT	=	Information Technology
LSP TMI	=	Lembaga Sertifikasi Profesi Teknik & Manajemen Industri (Industrial Engineering & Management Competence Certification Body
MES	=	Manufacturing Execution System
MGI	=	McKinsey Global Institute
OT	=	Operation Technology
PLC	=	Program Logic Control
PLN	=	Perusahaan Listrik Negara (State Electric & Power Distribution Company)
RAMI 4.0	=	Reference Architectural Model I4.0
RFID	=	Radio Frequency Identification
SCADA	=	Supervisory Control Data Acquisition
SIMMI 4.0	=	System Integration Maturity Model I4.0
SMI	=	Smart Manufacturing Industry
USA	=	United States of America
UTHM	=	University Tun Hussein Onn Malaysia
5V	=	Volume, Velocity, Variety, Value, Veracity

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Exploratory Survey Questionnaire	244
B	Interview Part 1 Protocol	251
C	Interview Part 2 Protocol	255
D	Interview Part 2 Protocol	259
E	Evaluation Survey Questionnaire	263
F	Dissemination of The Research	269
G	The Result from the exploratory survey	271
H	The Result from the Evaluation Survey	273
I	The Result of the Validity Test for Exploration Survey Instrument	274
J	The Result of The Reliability Test for Exploration Survey	276
K	The Result of The Validity Test for Evaluation Survey Instrument	277
L	The Result of The Reliability Test for Evaluation Survey	278
M	Cluster Analysis Of Exploration Survey Result	279
N	Cluster Analysis Of Evaluation Survey Result	283
O	VITA	287

CHAPTER 1

INTRODUCTION

1.1 Background of Study

I4.0, famously called 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, Industry 4.0 (I4.0) originated in 2011 from the German government's high-tech strategy of 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]. Almost 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. They believe that the I4.0 Concept is a strategy that becomes a platform for transformation and innovation through technology in the 4th Industrial Revolution era in this disruptive era.

Developed countries announced their national plan to adopt I4.0 earlier than developing countries to support national competitiveness. This action plan aims to secure a strong competitive position through technological innovation to enhance productivity, efficiency, and competitiveness. Germany announced a strategic initiative by issuing a high-technology 2020 action plan in November 2011, securing a powerful competitive position through technological innovation [4]. China launched an action plan to boost integrating informatization and industrialization in August 2013 [5].

This project purposed to explore the integration of informatization and industrialization. It continued in 2015 by announcing the program Made in China in 2025 [6]. The United States developed a framework for revitalizing American manufacturing in December 2009, then launched an Advanced Manufacturing Partnership (AMP), ensuring American leadership in global manufacturing competitiveness [3,7]. Likewise, other developed countries such as Canada, Europe, Japan, and others are competing to maintain their competitive position by developing their industrial transformation strategy.

In Southeast Asian Nations, Singapore ranks first in the policy launching timeline of I4.0 initiatives (see Figure 1.1) [8]. As is known, Singapore is a group of developed countries in economy, education, industry, and technology. Bloomberg Innovation Index ranked Singapore fifth globally in 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, according to the World Trade Organization [9]. So naturally, Singapore is moving faster in ASEAN to strengthen its competitiveness towards the transformation of I4.0, followed by Thailand, Malaysia, Vietnam, Indonesia, and the Philippines.

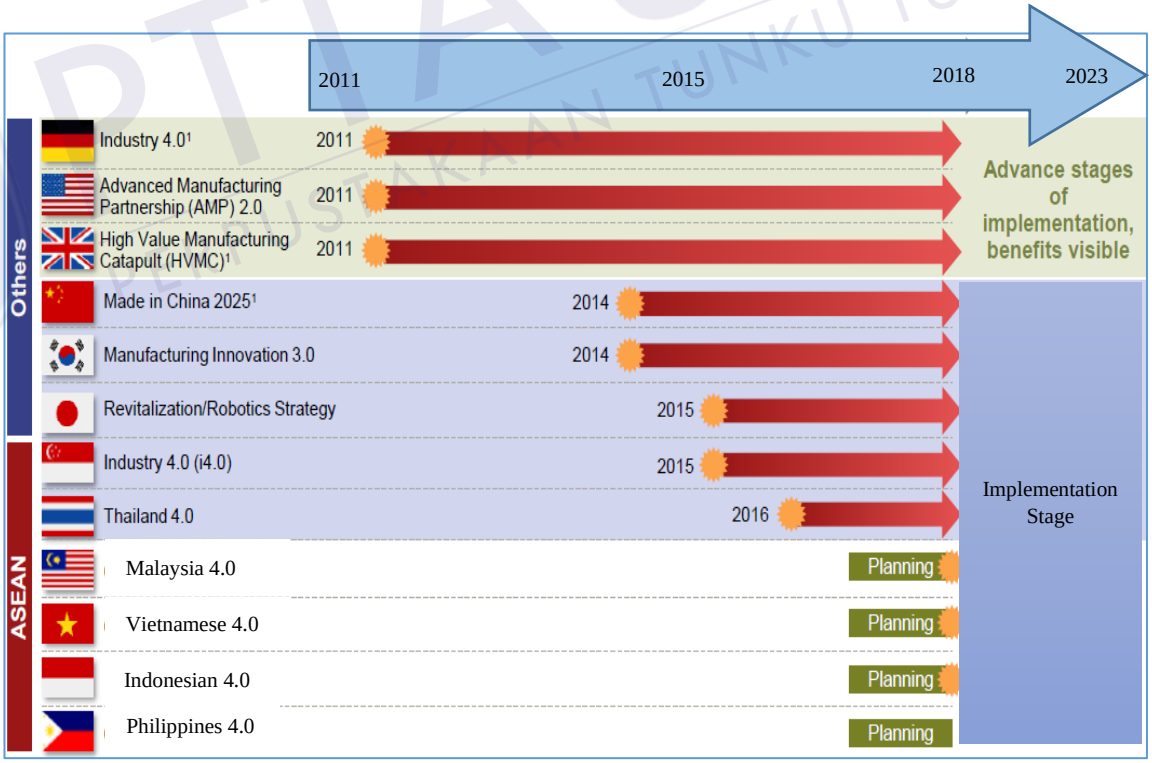

Figure 1.1: Starting Points of Policy Launch Timeline of I4.0 Initiatives in ASEAN & Others [211]

Figure 1.1 presents the timeline's history of how Indonesia is too late to launch a plan to adopt I4.0. As a developing country, Indonesia seems left behind in putting the I4.0 as a national plan to improve competitiveness, as shown in Figure 1.1. 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]. In Southeast Asia, Figure 1.1 shows Indonesia is a part of the group of countries, with Malaysia, Vietnam, and the Philippines categorized in the initial planning phase group in a low-rank position. Indonesia's I4.0 readiness roadmap is left behind in Southeast Asia, compared to Singapore, Thailand, Malaysia, and Vietnam, considering launching the policy timeline. It was reflected by the lower rank of Indonesia's readiness score of I4.0. Indonesia must improve its position and willingness to boost its competitiveness.

In the progress of 2023, for the implementation stage in Figure 1.1, Indonesia appears to be a country that is slow in responding to I4.0 compared to other countries in Southeast Asia. In the progress of plans for the development and implementation of I4.0 adoption in 2023, the United Nations, through UNCTAD (United Nations Conference on Trade and Development), released a report ranking 166 countries in the level of readiness to use frontier technology in Era I4.0 in the aspects of information and communication technology readiness, industry, research and development, finance and skills as shown in Table 1.1 (https://unctad.org/tir2023, UN Report 2023). This rating reflects the readiness of ASEAN countries towards I4.0 because readiness in adopting the leading technology parallel towards I4.0.

Table 1.1: The Ranking of 166 Countries' Readiness to Use Frontier Technologies in the I4.0 Era Based on Important Dimensions (UNCTAD Report 2023)

ASEAN Countries	Information & Communication Technology (ICT)	Industry	Research & Development	Finance	Skills
Singapore	7	4	17	17	8
Malaysia	30	7	28	16	64
Thailand	40	41	46	10	90
Brunei Darussalam	54	97	95	93	38
Vietnam	69	23	41	11	117
Philippine	94	3	52	80	79
Indonesia	102	47	50	97	107
Myanmar	132	101	107	118	143

In all fields, Table 1.1 shows Indonesia and Myanmar consistently in the group of three or four countries at the lowest rank in ASEAN.. Table 1.2 shows the ranking in ASEAN Countries.

Table 1.2: UNCTAD Innovation and Technology Report in Readiness to Use Frontier Technologies in ASEAN Countries (UNCTAD, Report 2023)

No	**Name**	**2023 rank**	**2021 rank**	**Change in rank**
1	Singapore	3	5	2
2	Malaysia	32	31	-1
3	Thailand	49	46	-3
4	Philippines	54	44	-10
5	Viet Nam	62	66	4
6	Brunei Darussalam	69	69	±0
7	Indonesia	85	82	-3
8	Myanmar	133	121	-12

Table 1.2 presents Indonesia's position in ASEAN as the lowest rank with Myanmar. Even compared to the previous year in 2021, it is still in the lowest rank. It is parallelly reflected in I4.0 readiness in ASEAN because essential and substantially applying frontier technology is about adopting I4.0.

Asian Development Bank has designed systematic indicators, namely the Global Index of Digital Entrepreneurship Systems (GIDES). It aims to assess the state of entrepreneurship across economies in the I4.0 era. This index measures the degree of digitalization in society and the economy and how it supports the entrepreneurial ecosystem. GIDES considers eight dimensions of the digital entrepreneurship environment: culture, institutions, market conditions, infrastructure, human capital, knowledge, finance, and networking, to contribute to index calculation, as shown in Table 1.3. The results of this measurement, directly and indirectly, reflect the readiness to adopt I4.0.

Table 1. 3: Global Index of Digital Entrepreneurship Systems (GIDES), Asian Development Outlook 2022 [12]

GIDES 2021 rank in ASEAN	Economy	GIDES 2021 score out of 100	GIDES 2021 ranks in 113 economies	GIDES 2021 classification
1	Singapore	81.3	1	Leader
2	Malaysia	43.1	27	Catcher-up
3	Thailand	25.9	59	Laggard
4	Vietnam	23.1	63	Laggard
5	Indonesia	20.4	71	Laggard
6	Philippines	18.5	79	Tailender

Table 1.3 shows Indonesia and the Philippines have the lowest rank and score in ASEAN for the Global Index of Digital Entrepreneurship Systems (GIDES). It indicates that environmental quality is conducive to supporting digital transformation and adopting I4.0. Indonesia left behind Singapore, Malaysia, Thailand, and Vietnam. Asian Development Bank designed this Instrument to provide a strategy for empowering entrepreneurship through digital transformation in I4.0. On the other hand, the United Nations (UN), through the Economic and Social Commission for Asia and the Pacific (ESCAPE), published a Digital Transformation Landscape Report

in July 2022. Indonesia again left behind Singapore, Malaysia, and Thailand but is better in the ranks than the Philipines and Vietnam.

Table 1.4: Digital Transformation Index, UN-ESCAPE Report 2022 [13]

Ranks	Country	Grade
4	Singapore	Special
31	Malaysia	A
46	Thailand	B
54	Indonesia	B
58	Philippines	B
63	Vietnam	B

Table 1.4 shows the ranks and grade ASEAN countries where Indonesia is in a low rank and Grade B besides Philipines and Vietnam. Indonesia needs to work hard toward digital transformation in the I4.0 era by improving its rank position to catch up with other countries in ASEAN, such as Singapore, Malaysia, and Thailand. This situation for Indonesia is an alarm to improve I4.0 transformation readiness as soon as possible because I4.0 is a concept to boost competitive advantage through innovation and technology.

The Indonesian Ministry of Industry stated that the adoption of I4.0 is to accelerate Indonesia's 2045 vision to become one of the countries with high income and Gross Domestic Product (GDP), the top 10 economies in the world by 2030 with the achievement of 10% Net Export contribution to GDP by regaining net export position, double productivity from 2018 by enhancing output while managing cost, and 2% of R&D spending share to GDP by building local innovation capabilities [8]. It motivated the Indonesian government to implement I4.0, especially in the manufacturing industry, which makes one of the most significant contributions to GDP.

For the manufacturing industry, I4.0 is vital for a long-term strategy to increase productivity and efficiency through empowering technology to increase competitiveness. It is in line with the vision of I4.0, which was first proclaimed in Germany that productivity, efficiency, and competitiveness could be achieved by enabling employees to control, manage and configure a network of intelligent manufacturing resources and manufacturing steps based on situations and targets

flexibly, employees will be freed from doing routine tasks, allowing them to focus on creative, value-added activities. As such, they will retain a key role, particularly in quality assurance. At the same time, flexible working conditions will allow for an excellent match between employees' work and personal needs [3]. In other words, I4.0 is the concept of technological transformation and other resources to help the industry be more productive, agile, and efficient [14]

In adopting I4.0, The Government proposed Indonesia Making 4.0 by developing the Instrument of Indonesia I4.0 Readiness Index to measure the industry readiness to adopt I4.0 [10]. This project involves academics, practitioners, industry professionals, researchers, experts, and leading global consultants, such as McKinsey and The Fraunhofer Institute. The fundamental aspects of this instrument have specific assessments in five dimensions as the primary measure for assessing I4.0 readiness.

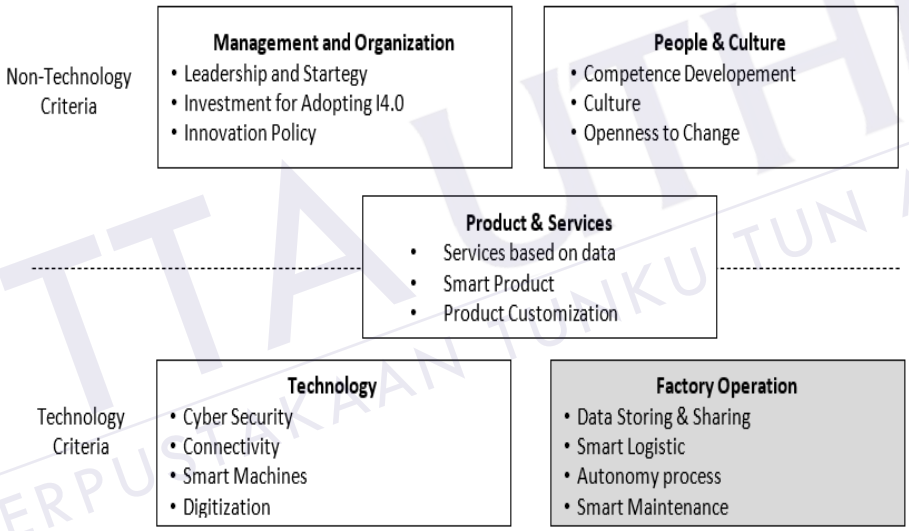

Figure 1.2: The Five Dimensions of the Indonesia I4.0 Readiness Instrument [10]

Figure 1.2 shows the INDI 4.0 structure comprising five dimensions (factory operation, technology, management, organization, people, culture, products, and services). It applies nationally to five priority industry sectors: automotive, textiles, electronics, chemicals, and foods. The criteria levels in Indonesia I4.0 Readiness Instrument are from level 0 to 4, meaning 0=not ready, 1=early readiness, 2=intermediate readiness, 3=mature readiness, and 4=implemented. In initial observation, The Government of Indonesia first applied Figure 1.2: The Five Dimensions of the Indonesia I4.0 Readiness Instrument to some manufacturers to obtain knowledge of the current I4.0 readiness. Figure 1.3 shows the readiness levels

of some manufacturers in the initial Indonesia I4.0 Readiness Instrument project in 2018.

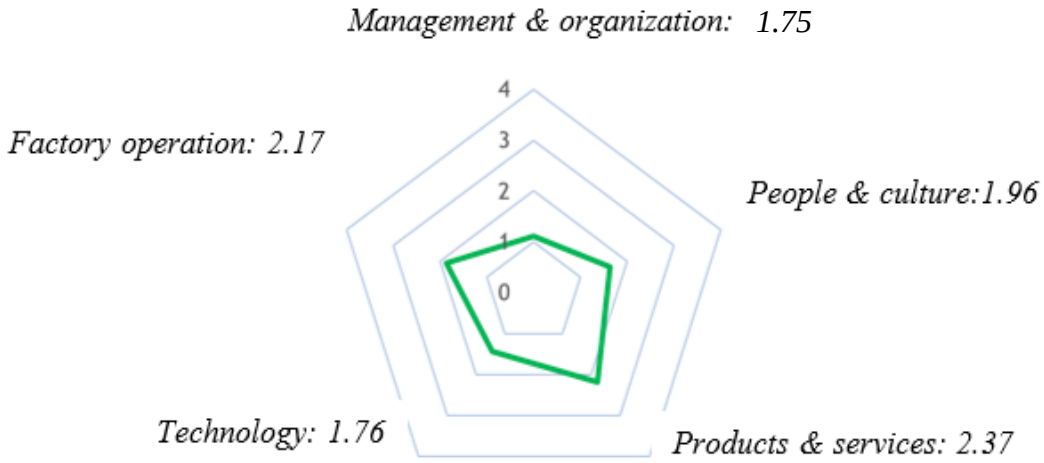

Figure 1.3: The Initial Results of the Assessment Using Indonesia I4.0 Readiness Instrument [10]

In general, Figure 1.3 reflects that the readiness of industries in Indonesia to transform towards I4.0 is at a low-level score with a total average score of 2.00 (scale from 0.00 to 4.00). This readiness level was assessed at the beginning of the I4.0 project started. The Indonesia I4.0 Readiness Instrument assessment involved only 25 companies selected by the government to be applied at the start of the project. The government performed this first assessment as an initial observation to determine the extent to which the adoption of I4.0 occurred in the national industry as an initial policy plan. Until 2022, the Government has conducted an I4.0 assessment of 903 companies [15].

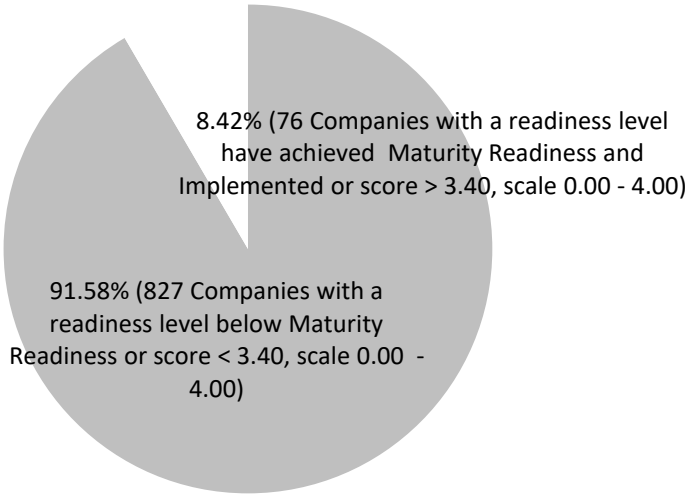

Figure 1. 4: Number of Companies Assessed I4.0 Readiness in Indonesia [15]

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APPENDIX O

VITA

The author was born on April 15, 1973, in Bekasi, West Java, Indonesia. He went to Sekolah Menengah Negeri 1 (SMAN I) Karawang, West Java, for his secondary school. He pursued his diploma at the Academy of Electromedic Depkes RI Jakarta, Indonesia, and graduated with a Diploma of Engineering in Electromedic. Upon graduation, he worked as a Quality Assurance Staff at PT Epson Indonesia Industry, then joined Johnson Controls as a Quality Assurance Engineer. He then enrolled at the Sahid University, Jakarta, where he was awarded a Bachelor of Industrial Engineering in 2000. After that, he got a scholarship from ILO Japan to study Japanese work ethic and culture, 5S, and production supervisory at Chiba Polytechnic Center, Tokyo, Japan. When he finished studying in Japan in 2021, he attended a Master of Industrial Engineering at the Institute of National Technology and Science Jakarta (ISTN) and graduated in 2003, then came back to Japan for training in just in time, kanban system and inventory control in Aisan Toyota Training Center Nagoya Japan. Furthermore, after returning to Indonesia, he worked in the manufacturing and logistics industry for companies such as Aisan, Connels Bro, and Schenker. Since 2013, he has been a lecturer for some subjects of Industrial Engineering in the Faculty of Engineering, Industrial Engineering Study Program, Universitas Mercu Buana. He attended and graduated Doctoral program in Human Resources Management at State Jakarta University (UNJ) and a Ph.D. Program in Mechanical and Manufacturing Engineering Faculty at Universiti Tun Hussein Onn Malaysia (UTHM). He is currently the Assessor and Certification Manager of the Industrial Engineering Competency in Profession Certification Board in Industrial Engineering, Halal Auditor and Mentor in the Drug, Cosmetic and Food Monitoring Agency of Ulema Council, Jakarta, and also actively participating in research about digital transformation, Indusyttr 4.0 and smart city.