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INDUSTRY 4.0 READINESS AND ROADMAP IN FOOD INDUSTRY: INSIGHTS FROM INDONESIAN MANUFACTURING ENTERPRISES USING EXPLANATORY SEQUENTIAL MIXED-METHOD DESIGN

Iman Rahmatulloh[1], Siska Noviaristanti[2], Muhammad Awaluddin[3]
[1,2,3,] School of Economics and Business, Telkom University, Bandung, Indonesia
Email: imanrahmatulloh@student.telkomuniversity.ac.id

ABSTRACT

The paper aims to understand the current readiness level of Industry 4.0 in the food industry. Furthermore, the study explores the prioritized Industry 4.0 dimensions and initiatives needed to improve the readiness level. The study uses an explanatory sequential mixed-method design. In the quantitative phase, the Industry 4.0 readiness assessment was conducted using the Smart Industry Readiness Index framework. The quantitative study further explores the prioritized dimensions using The Prioritization Matrix framework. In the qualitative phase, interviews with industry practitioners from the participating companies were conducted to gain more understanding and propose the conceptual roadmap. The study found that the Indonesian food industry has a better average readiness than the global average but significantly lower than the best-in-class manufacturers. Vertical Integration, Shop Floor Intelligence, Shop Floor Automation, and Workforce Learning & Development are four priority dimensions to increase the readiness level in the food industry. A conceptual roadmap was proposed to improve the readiness index based on the strategic planning horizon, prioritized dimensions, and initiatives identified from interview results. The results of this study would provide an additional reference for applying explanatory sequential mixed-method design. The prioritized dimensions found would also benefit other researchers in the development of the readiness or maturity model. This paper provides a deeper understanding of Industry 4.0 readiness, the prioritized dimensions, and related improvement initiatives to propose the strategic roadmap for the food industry by utilizing explanatory sequential mixed-method design..

KEYWORDS *Industry 4.0, Readiness Index, Roadmap, Food Industry, Mixed Method*

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INTRODUCTION

Industry 4.0 is a disruptive phenomenon widely studied in recent literature (Galati and Bigliardi, 2019). Industry 4.0 was first introduced at the Hannover Fair in 2011 as part of a project initiated by the German government to promote digital technologies in the manufacturing sector to increase production efficiency in the German industry (De Propis and Bailey, 2020; Schwab, 2017; Sung, 2018). The term describes the fourth industrial revolution, driven by the development of increasingly integrated and powerful digital technologies. These technological developments enable the creation of an intelligent factory that can bring together a manufacturing system's physical and virtual aspects to work flexibly. The implementation of Industry 4.0 facilitates massive product customization and the creation of new operating models (Schwab, 2017).

Several countries worldwide, including the United States, France, the United Kingdom, South Korea, China, Japan, and Singapore, have adopted Industry 4.0 as part of their national strategic plan (Liao *et al.*, 2017). For Indonesia, the fourth industrial revolution, or Industry 4.0, allows the revitalization of the manufacturing sector. It is one of the ways to accelerate the achievement of Indonesia's vision to become a country with the 10th global economic position by 2030. Indonesia's government launched the Making Indonesia 4.0 initiative in 2018 to achieve its vision. Making Indonesia 4.0 prioritizes the implementation of Industry 4.0 in five manufacturing industries, including the food and beverages industry (Kementerian Perindustrian Republik Indonesia, 2018). The food and beverages industry was also included in the global Industry 4.0 assessment conducted by the World Economic Forum in 2022. Based on the assessment results, it is apparent that the food and beverages industry has a relatively low Industry 4.0 readiness level compared to more advanced industries (World Economic Forum, 2022).

Studies have been conducted by researchers to assess Industry 4.0 readiness or maturity level in the food industry. During 2017-2021, the assessment campaign involving the food, beverages, and tobacco industry was observed in 7.19% of the Industry 4.0 readiness or maturity assessment published papers (Flamini and Naldi, 2022). The percentage is relatively small compared to other industries observed. Another attempt was conducted by Sarı et al. (2020), who assessed the Turkish manufacturing industry, including the food and beverages industry. The assessment focuses more on awareness of Industry 4.0-related technologies (Sarı *et al.*, 2020). On the other hand, the study related to the Industry 4.0 readiness model is growing exponentially (Botha, 2018). This paper tries to take a different approach to fill the gap in the Industry 4.0 assessment campaign, focusing on an empirical study to gain a deeper understanding of the current Industry 4.0 readiness level and a proposed roadmap for the food industry.

Literature Review

Industry 4.0

Industry 4.0 (also referred to as digitization of manufacturing) is characterized by cyber-physical systems, automation, and data exchange. It is no longer a future trend and is being employed worldwide by manufacturing organizations to gain benefits of improved performance, reduced inefficiencies, and lower costs while improving flexibility (Butt, 2020). Industry 4.0 is currently a top priority for many organizations, research centers, and universities (Ghobakhloo, 2018). Autonomous vehicles, 3D printing, advanced robotics, Internet-of-Things (IoT), and blockchain are some of the technological trends that drive the fourth industrial revolution (Schwab, 2017). To support the development of Industry 4.0, the German Electrical and Electronic Manufacturer's Association (ZVEI) developed the Reference Architecture Model Industrie 4.0 (RAMI 4.0), which has begun to be adopted globally. RAMI 4.0 is intended to provide all stakeholders involved in Industry 4.0 discussions and activities with a common concept that can be understood by each other, thereby increasing opportunities to develop new products and business models (Lydon, 2022). The applications of RAMI 4.0 and Industry 4.0 component models can be found in the Cyber-Physical Production System (CPPS), which consists of sub-systems that are connected within and across all levels of production (Lin *et al.*, 2019).

Industry 4.0 Readiness Model

Companies that aim toward digital transformation have to be ready to make changes in enterprise operations and processes and, therefore, need to have strong capabilities (Dikhanbayeva *et al.*, 2020). Among the tools that are widely used to measure capability is through maturity models. They are designed as the logical path represented by separate maturity levels so that the most mature company is the one that possesses all the capabilities to reach its objectives. (Dikhanbayeva *et al.*, 2020). Several models have been developed both by academics and industry practitioners. Schumacher et al. (2016) have developed a maturity model with nine dimensions using the grounded theory method. Schuh et al. (2020) developed the ACATECH Industrie 4.0 Maturity Index, which contains six values-based development stages and four structural areas. Antony et al. (2023) developed a maturity model using grounded theory with exploratory sequential mixed-method design. The academic maturity models are publicly available for external users but are often incomplete or underdeveloped. Meanwhile, the well-established commercial maturity models provide a comprehensive evaluation of firms' readiness or maturity, but access to full methodology is restricted (Dikhanbayeva *et al.*, 2020). In 2018, Singapore EDB developed The Smart Industry Readiness Index to measure Industry 4.0 readiness across multiple industries. The Smart Industry Readiness Index (SIRI) is a convenient method to evaluate the maturity of enterprises (Lin and Wang, 2021). SIRI drew reference from the RAMI 4.0 framework and was validated by an advisory panel of academic and industry experts (Lin *et al.*, 2019). SIRI has been used to assess 600 (six hundred) companies globally across 14 (fourteen) industries (World Economic Forum, 2022).

Industry 4.0 Roadmap

The conversation around Industry 4.0 has evolved from learning about its key concepts and benefits to exploring how to implement the best transformation roadmaps (Singapore Economic Development Board, 2020a). From a strategy and technology perspective, the transition to Industry 4.0 requires a comprehensive strategic roadmap that can visualize each step towards a digital manufacturing enterprise (Sarvari *et al.*, 2018). Roadmapping is an important method that has become part of the creation and development of strategy and innovation in various companies (Ghobakhloo, 2018). Manufacturing companies can use the maturity model to develop a digital roadmap that is precisely tailored to their individual needs and can be used to implement Industrie 4.0 and transform the company into a learning, agile organization (Schuh *et al.*, 2020).

RESEARCH METHOD

This study uses an explanatory sequential mixed-method design to explore the phenomenon. The integration of quantitative and qualitative data will yield additional insight beyond the information provided by either the quantitative or qualitative alone (Creswell and Creswell, 2018). In the first phase, we assessed the readiness index of Industry 4.0 using the Smart Industry Readiness Index (SIRI) framework on seven enterprises in the food and beverage industry. The Smart Industry Readiness Index is a convenient method to evaluate the maturity of enterprises (Lin and Wang, 2021). SIRI has been used to assess 600 (six hundred) companies globally across 14 (fourteen) industries (World Economic Forum, 2022). Thus, it provides a practical method to assess Industry 4.0 readiness or maturity level.

In the second stage of the quantitative phase, SIRI The Prioritization Matrix was used to calculate impact values for 16 (sixteen) SIRI dimensions to find the most impactful dimensions to be prioritized. The Prioritization Matrix framework was designed as a management planning tool to assist companies in quantitatively identifying the high-priority SIRI Dimensions in which improvements will bring the most benefit, by comparing the Impact Values across the different SIRI Dimensions (Singapore Economic Development Board, 2020a).

In the qualitative phase, the results from the quantitative phase were further explored. This study used a grounded theory methodology to explore the factors influencing the current readiness level of Industry 4.0 and what initiatives or steps can be taken to improve its current level. Grounded theory methodology is primarily developed to derive an explanation about a phenomenon that was non-existent or where the theoretical explanation was inadequate (Antony *et al.*, 2023). The methodology used in this study is shown in Figure 1.

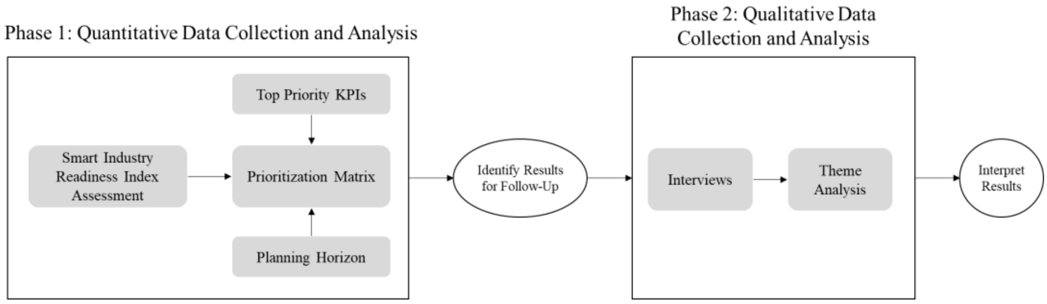

Figure 1 – Research Design

Source(s): (Adapted) (Creswell and Creswell, 2018; Singapore Economic Development Board, 2020b, 2020a)

Quantitative data collection and analysis

Invitations to participate in the research were emailed to large enterprise companies based on Ministry of Industry of the Republic of Indonesia data. Seven large enterprise companies in the food and beverage industry are willing to participate in conducting a self-assessment of the Industry 4.0 readiness index. Based on the number of full-time employees, six participating companies have more than 300 workers, while the other has 100 to 300 workers. Meanwhile, based on the main industry sector, two companies are in the milk and ice cream processing industry, two companies are in the cocoa and chocolate processing industry, one company is in the oil processing industry, one company is in the flour and starch processing industry, and one company is in the flavoring industry. Flamini and Naldi (2022) study found that around 45% of published Industry 4.0 assessment campaign articles during 2017-2021 involved less than ten companies.

Online questionnaires were sent to the company representative to assess the maturity level of 16 SIRI dimensions as well as collect the top priority KPIs selection and Industry 4.0 planning horizon for their organization. The collected assessment score was then summarized to get the average score of the Industry 4.0 readiness index in the Indonesian food industry. Subsequently, the impact values were calculated using steps and formulation from The Prioritization Matrix framework. The determination of the prioritized dimensions was carried out in two steps: (1) select the dimensions with the highest impact values from each building block, namely the Process area, Technology area, and Organization area; (2) Select an additional dimension with the highest impact values from the remaining 13 (thirteen) dimensions; (Singapore Economic Development Board, 2020a).

Qualitative data collection and analysis

In research that uses the explanatory sequential design, the qualitative research phase is used to understand more deeply the results of quantitative research, so it is very important to link the results of quantitative research with data collection conducted in the qualitative phase (Creswell & Creswell, 2018). The interview questions were built based on the results in the quantitative phase, namely measuring the current level of Industry 4.0 readiness and the dimensions that are prioritized to be improved by companies in the food and beverage industry to increase the level of Industry 4.0 adoption. Interviews were conducted with three industry practitioners from participating companies in the first phase of the research. The industry practitioners selected were senior managers with more than 15 (fifteen) years of experience in the food and beverage industry. The results of the interviews were coded to obtain themes and sub-themes from the reduced data that have a close relationship in explaining the results of the research in the quantitative phase (Creswell & Creswell, 2018; Sugiyono, 2021).

RESULT AND DISCUSSION

In the first section, the current readiness index of Indonesian food and beverage manufacturing enterprises is presented and interpreted based on the Smart Industry Readiness Index maturity level description. Benchmarking was also presented and discussed to give an overview of Indonesia versus global food and beverage industry readiness. Subsequently, the calculation results of priority dimensions based on The Prioritization Framework are discussed. In the third section, the themes and sub-themes identified from the interviews in the qualitative phase are presented and discussed further in the fourth and fifth sections. The last section will present the proposed roadmap for improving Industry 4.0 in the food and beverages industry.

Industry 4.0 readiness index

The readiness index average value of each dimension measured from the seven participating companies is presented in Figure 2. The average value provides an overview of the Industry 4.0 readiness index for Indonesian food and beverages manufacturing enterprises. Comparing the results of the Industry 4.0 readiness index within the same framework with the global companies is essential in understanding the positions of the food and beverage industry in Indonesia to achieve its goal "*To Become The Food and Beverages Powerhouse in ASEAN.*". In comparison to the global benchmark, Figure 2 also presents the average global readiness index and best-in-class readiness index taken from the SIRI global assessment of 600 global companies in 14 industrial sectors, including the food and beverage industry (World Economic Forum, 2022).

Indonesian food and beverage companies have an average readiness index of 1.83, while the average global food and beverage company has a readiness index of 1.09, and global food and beverage companies in the best-in-class category have a readiness index of 3.38. In general, the level of readiness of food and beverage companies in Indonesia has a higher value than the global average. However, it is still much lower than the companies in the best-in-class category.

The difference between the average value of companies in Indonesia and the global average can be influenced by the scale of companies participating in the assessment. In the assessment conducted by the World Economic Forum, participants consisted of 44% of multinational companies (MNCs) and 56% of Small-Medium Enterprises (SMEs) (World Economic Forum, 2022). Meanwhile, the focus of the research conducted in this paper is limited to Large Enterprises. The difference in readiness index between MNCs and SMEs can be seen in the assessment results of the World Economic Forum (2022), with MNCs scoring higher by half or one full scale of the readiness index. Different results are shown by global companies in the best-in-class category that outperform food and beverage manufacturing enterprises in Indonesia by one or two-and-a-half readiness scales. The factors that influenced this current stage of the readiness index were further explored in the interview with industry practitioners and discussed in the qualitative results section.

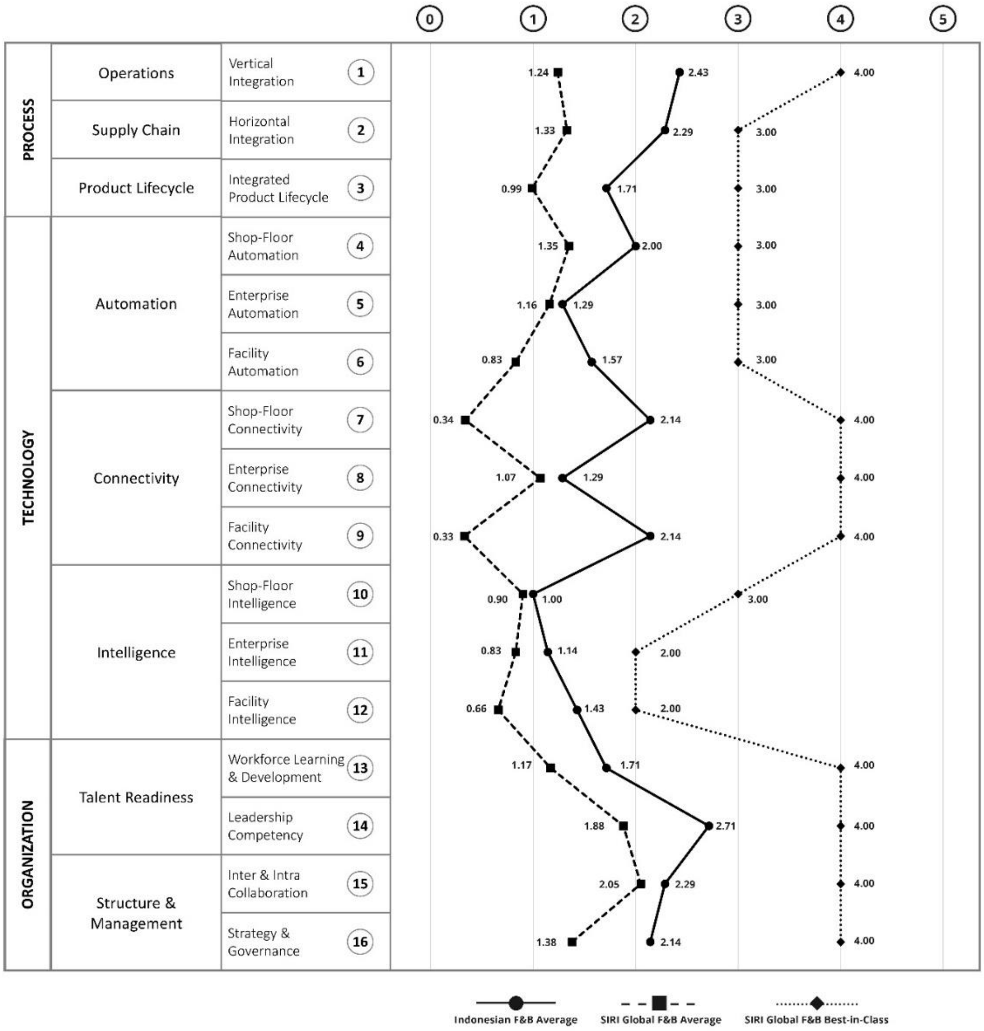

Figure 2 –Industry 4.0 Readiness Index Benchmark
Source(s): (Author own elaborations, 2024; World Economic Forum, 2022; Singapore Economic Development Board, 2020a)

Prioritized dimensions to improve Industry 4.0 readiness

The next stage in the quantitative phase is to determine the dimensions of the readiness index assessment results that must be prioritized to improve the implementation of Industry 4.0 in the food and beverage industry. Priority calculation uses the Prioritization Matrix framework, which is part of the SIRI framework. The primary information used as input in the Prioritization Matrix method is the average assessment results of the 16 SIRI dimensions that have been carried out in the first stage of the research, information on five Key Performance Indicators (KPIs) that are prioritized for the food and beverage industry that participants have selected, Planning Horizon information that describes the strategic timeframe for Industry 4.0 implementation for the food and beverage industry that participants have selected, and the best-in-class Global SIRI assessment benchmark in the food and beverage industry sector published by the Singapore Economic Development Board in 2020.

	Process			Technology									Organization			
	Vertical Integration	Horizontal Integration	Integrated Product Lifecycle	Shop Floor Automation	Enterprise Automation	Facility Automation	Shop Floor Connectivity	Enterprise Connectivity	Facility Connectivity	Shop Floor Intelligence	Enterprise Intelligence	Facility Intelligence	Workforce Learning & Development	Leadership Competency	Inter- & Intra Company Collaboration	Strategy & Governance
Average Readiness Index	2.4300	2.2900	1.7100	2.0000	1.2900	1.5700	2.1400	1.2900	2.1400	1.000	1.1400	1.4300	1.7100	2.7100	2.2900	2.1400
Industry Best-in-Class	4.0000	3.0000	3.0000	3.0000	3.0000	3.0000	4.0000	4.0000	4.0000	3.0000	2.0000	2.0000	4.0000	4.0000	4.0000	4.0000
Proximity Factor	1.5714	0.7143	1.2857	1.0000	1.7143	1.4286	1.8571	2.7143	1.8571	2.0000	0.8571	0.5714	2.2857	1.2857	1.7143	1.8571
Normalized Proximity Factor	**0.0636**	**0.0289**	**0.0520**	**0.0405**	**0.0694**	**0.0578**	**0.0751**	**0.1098**	**0.0751**	**0.0809**	**0.0347**	**0.0231**	**0.0925**	**0.0520**	**0.0694**	**0.0751**
KPI Factor	13.0000	3.0000	7.0000	13.0000	6.0000	10.0000	7.0000	4.0000	6.0000	15.0000	8.0000	10.0000	9.0000	9.0000	9.0000	5.0000
Normalized KPI Factor	**0.0970**	**0.0224**	**0.0522**	**0.0970**	**0.0448**	**0.0746**	**0.0522**	**0.0299**	**0.0448**	**0.1119**	**0.0597**	**0.0746**	**0.0672**	**0.0672**	**0.0672**	**0.0373**
Weighted KPI Factor	0.0388	0.0090	0.0209	0.0388	0.0179	0.0299	0.0209	0.0119	0.0179	0.0448	0.0239	0.0299	0.0269	0.0269	0.0269	0.0149

Weighted Proximity Factor	0.0191	0.0087	0.0156	0.0121	0.0208	0.0173	0.0225	0.0329	0.0225	0.0243	0.0104	0.0069	0.0277	0.0156	0.0208	0.0225
Impact Values	**0.0579**	**0.0176**	**0.0365**	**0.0509**	**0.0387**	**0.0472**	**0.0434**	**0.0449**	**0.0405**	**0.0691**	**0.0343**	**0.0368**	**0.0546**	**0.0425**	**0.0477**	**0.0375**

Table 1 – Prioritization Matrix Calculation

This study could not include other information, such as cost ratios, due to confidentiality considerations for participating companies. The calculation results of the prioritization matrix are presented in Table 1.

The majority of participating companies in this study chose a strategic planning horizon between three to five years in the implementation of Industry 4.0. This shows that large companies tend to choose long-term planning in developing a transformation roadmap because of the support of financial, human resources, and experience (World Economic Forum, 2022). This planning horizon will affect the strategy formulation stage, which focuses on activities such as identifying opportunities and threats from the organization's external environment, understanding the organization's internal strengths and weaknesses, setting long-term goals, developing various alternative strategies, and choosing a strategy to implement. The strategy selection will affect the organization's competitive advantage (David, 2011). Another critical element used in the prioritization matrix formulation is the KPIs factor. The five top priority KPIs selected for Indonesian food and beverage companies are asset and equipment efficiency, materials efficiency, product quality, process quality, and safety. Each KPI has a different degree of relevance that contributes to the final calculation of impact values for each readiness index dimension. For Indonesian and global food and beverage manufacturers, asset and equipment efficiency, materials efficiency, and product quality are the top priorities. Those top KPIs reflect manufacturing companies whose primary activity is to produce goods.

Based on the calculation, this study suggests four dimensions as priorities to improve for the food and beverage industry, namely Vertical Integration with an impact value of 0.0579, Shop Floor Intelligence with an impact value of 0.0691, Shop Floor Automation with an impact value of 0.0509, and Workforce Learning & Organization with impact values 0.0546. The initiatives needed to improve those dimensions were further explored in the interview with industry practitioners and discussed in the qualitative results section.

Industry 4.0 current readiness and improvement initiatives themes

The results of qualitative data analysis resulted in two main themes in the "*Industry 4.0 in Food & Beverages Industry*" domain. The first theme is related to the current state of Industry 4.0 maturity level, namely "*Factors Influencing Current Stage of Industry 4.0 Maturity*", and the second one is related to the initiatives needed in developing the Industry 4.0 implementation roadmap, namely "*Initiatives to Improve Industry 4.0 Maturity*". Figure 3 shows the identified themes and sub-themes.

The first theme has nine sub-themes divided into two groups, namely "Industry 4.0 Adoption Driving Forces" with sub-themes "Potential Benefit of Industry 4.0", "Global COVID-19 Pandemic" and "Government's Industry 4.0 Initiatives". The other theme group is "Industry 4.0 Adoption Challenges" with sub-themes "Talent Gap", "Organizational Changes", "Burden of Current Technology Level", "Capital-Intensive in Technology Investment", "Indonesia Industry 4.0 Ecosystem", and "F&B Manufacturing Process Characteristic". While the second theme has thirteen sub-themes incorporated into three groups, namely "Improving Vertical Process Integration" with the sub-themes "Implementation of MES System", "Implementation of Planning & Scheduling System", and "Cybersecurity Enhancement". Then, the "Improving Workforce Learning & Development" group with sub-themes "Upskilling or Reskilling Existing Employees", "Job Rotation for Existing Employees", "Partnership with Labor Union for Job Role Changes", and "Qualification Adjustment for New Employee Recruitment". Furthermore, the last one is "Improving Intelligence and Automation Technology" with sub-themes "Implementation of Big Data Infrastructure", "Data Analytics with Machine Learning & AI", "Integrating Machine Learning & AI with PLC System", "Connecting PLC to Database through IoT to Enable Data Acquisition", and "Connecting PLC to PLC for Complex Automation System".

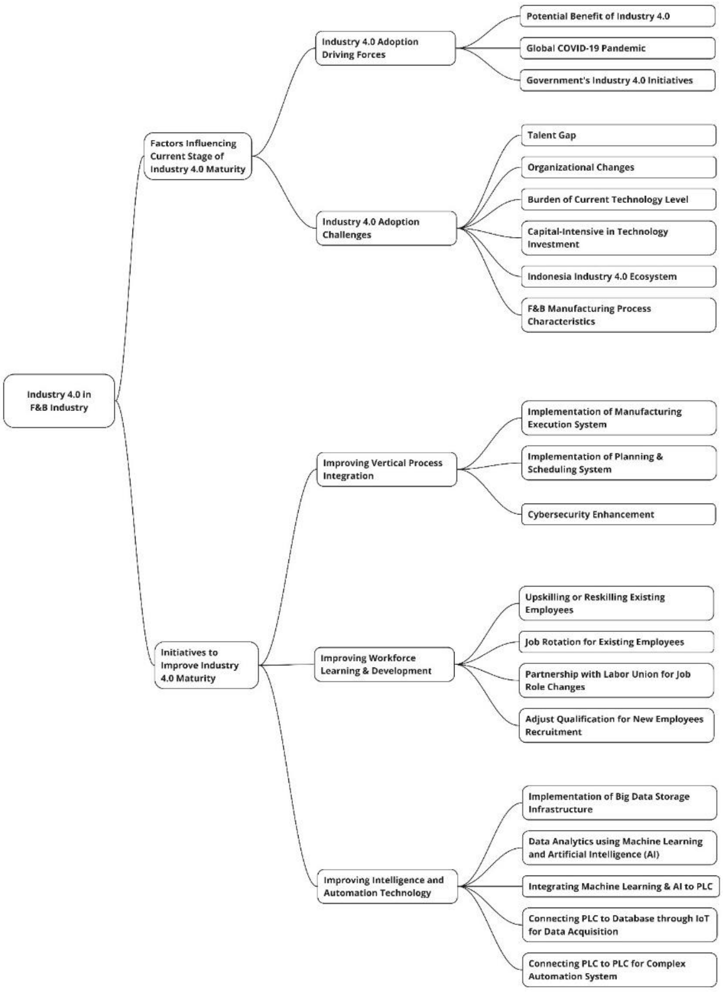

Figure 3 - Industry 4.0 in Food Industry Themes and Sub-themes
Source(s): (Authors own elaboration, 2024)

Factors influencing the current stage of Industry 4.0 readiness

The current stage of Industry 4.0 adoption in Indonesia's food and beverage manufacturing enterprises is driven by several factors. One of the factors identified from interviews with industry practitioners is the potential benefits of Industry 4.0 implementation on business performance. These potential benefits include speed in decision-making, increased efficiency and productivity, improved product quality, and improved service quality to consumers.

"So, for industry 4.0, in my opinion, for the food and beverage sector, it helps to make it more transparent and faster in decision-making." **Interviewee 1**

"Industry 4.0 should be able to improve the performance of the company, for example, productivity, efficiency is definitely yes, maybe the quality of the product can be better controlled, so maybe and also more efficient, of course, maybe also with that means unnecessary costs can be reduced, including, for example, reducing rejects, reducing waste" **Interviewee 2**

Those factors aligned with the findings from Romanello & Veglio (2022) that suggest the adoption of Industry 4.0 in the food processing industry sector positively impact product quality, process effectiveness, and strategic planning. Other factors that encourage the adoption of Industry 4.0 in Indonesia are the COVID-19 pandemic and programs launched by the government to achieve the Making Indonesia 4.0 initiative.

"We have to transform with digital faster because of the pandemic conditions." **Interviewee 1**

"We got the opportunity to join the Indonesian government program in collaboration with Germany" **Interviewee 2**

The adoption gap that occurs in the Process area between food and beverage companies in Indonesia and the best-in-class global companies can be influenced by unique characteristics of the manufacturing process in the food and beverage industry, which are seen as challenging to implement.

"But there is indeed something else in the food industry. There are other factors that we cannot do yet, and we cannot make it standardized. And it is probably because it cannot be standardized like we cook. We cook the same way, and the stove has the same settings, but the results may differ. Maybe this is one of the factors." **Interviewee 2**

However, a different approach is taken by the best-in-class global companies that have adopted Industry 4.0 technology to integrate and automate processes. One of the use cases implemented by one of the global food and beverage companies from the Global Lighthouse Network of the World Economic Forum is AI-enabled taste assurance with parameters close-loop optimization; this initiative boosts labor performance with a reduction of 96% labor work-hours per tonne (World Economic Forum, 2023).

In the Technology area, with the main pillars of Automation, Connectivity, and Intelligence, the best-in-class global companies significantly outperform food and beverage companies in Indonesia, with the most significant difference being on the Connectivity pillar. The high investment cost required to adopt Industry 4.0 technologies is one of the barrier factors highlighted by industry practitioners in

Indonesia. Horváth and Szabó (2019) and Romanello and Veglio (2022)also found similar factors.

"It must be realized that transforming towards industry 4.0 is not cheap; it is costly, and the justification is rather difficult to determine the return." **Interviewee 1**

"Need an effort to invest in installing certain devices such as sensors." **Interviewee 3**

In addition to financial considerations, the practitioners highlight technical barriers in the form of different levels of technology installed between one machine and another in the production area. The difference in the technological level is a burden that must be resolved when adopting the latest technology of Industry 4.0.

"The implementation cannot be forced because the factories come with different backgrounds, from different years, to standardize one technology, one factory, and another factory are not the same; the challenges are different." **Interviewee 1**

Therefore, the managers need to balance between using legacy technology and updating to the new technology so that company resources can be allocated appropriately (Tabim *et al.*, 2021). Differences in technology generation can also result in a lack of standardization in communication protocols between machines, which can be an obstacle to adopting Industry 4.0 technologies (Horváth and Szabó, 2019). In adopting new technologies to support Industry 4.0, Horváth and Szabó (2019) suggest that the difficulty in evaluating the right technology products is one of the challenges for companies. Industry practitioners also see the same thing in Indonesia.

"One of the other factors is determining the product, determining the partner. Product selection may not be easy. It takes a study." **Interviewee 1**

In the Organization area, lack of knowledge related to Industry 4.0 and willingness to learn new technology trends are highlighted by industry practitioners as factors that hinder talent development.

"Awareness is still very lacking. Because in college, for example, at the university, not all of them are taught like that, although maybe the generations are already digital, but maybe this kind of awareness (Industry 4.0) is still very lacking." **Interviewee 2**

"The willingness of the workers themselves to learn. Because it is not forced, (but) asked to shift their comfort zone." **Interviewee 1**

Challenges in the organizational aspect are highlighted by industry practitioners, especially in changing the way organizations collaborate and developing a broad Industry 4.0 strategy, including the need for changes in mindset, changes in the ways of working, and the complexity of an Industry 4.0 implementation project.

"The way they work must also be changed, must change their mindset because I think this is also a big challenge in terms of changing the way of people work because the demand is to keep up with the technological trends in the future." **Interviewee 3**

"There are indeed those (projects) that can be implemented easily, can be done quickly, but sometimes there are those that have to change the mindset, change the organization, change the way between departments interact." **Interviewee 1**

These challenges are common factors in the organizational area that are also identified in other studies such as in Dutta et al. (2022), Horváth & Szabó (2019), Machado et al. (2019), Romanello & Veglio (2022) and Tay et al. (2021).

Initiatives to improve Industry 4.0 readiness

The study in the quantitative phase suggests four SIRI dimensions that need to be prioritized to improve the readiness index and adoption of Industry 4.0 in the food and beverage companies in Indonesia. Initiatives that could be taken by managers are discussed in the following sections.

Vertical Integration

Vertical integration is the integration of processes and systems across all hierarchy levels of the automation pyramid within a facility to establish a connected, end-to-end data thread (Singapore Economic Development Board, 2020b). Vertical integration is one of the key principles in implementing Industry 4.0 (Tabim *et al.*, 2021). Vertical integration provides more transparency and control of the production process and helps to improve the shop floor decision-making process (Frank *et al.*, 2019).

Industry practitioners suggest that the implementation of the Manufacturing Execution System (MES) and the implementation of the Advanced Planning and Scheduling (APS) system can improve the current readiness level of the vertical integration dimension.

"It depends on the purpose; four levels (Automation Pyramid Level 1, 2, 3, and 5) are good enough to get to the world-class, but if the companies are still small or not yet complex, maybe there is no need for MES (Manufacturing Execution System).” **Interviewee 1**

“For consumer business, retail, or seasonal, planning (system) is important because of commodity problems. Secondly, maybe the capacity is not as big as the demand during the high season. So buffering is also important. If you do not use planning (system), it is not easy. We will lose the opportunity.” **Interviewee 1**

The findings aligned with the study conducted by Tabim et al. (2021) to understand what systems need to be integrated to implement vertical integration. The study found that vertical integration is represented through the integration of several key systems at various operational layers such as SCADA (Supervisory Control and Data Acquisition), MES (Manufacturing Execution System), ERP (Enterprise Resource Management) as well as APS (Advanced Planning and Scheduling) and PLM (Product Lifecycle Management) systems. With the integration and connectivity between systems in vertical integration, the aspect of network security or cybersecurity is raising concerns for industry practitioners.

“The most felt is in the aspect of security, actually. When data flows through the OT (Operational Technology) to the IT (Information Technology) network, when the data has entered the level of global connections, for example, the cloud which can be accessed anywhere.” **Interviewee 1**

“Become vulnerable when you are connected to the internet because it can be accessed anywhere.” **Interviewee 1**

Qian et al. in Tabim et al. (2021) see that cybersecurity is one of the factors that prevent companies from developing the level of integration in vertical integration due to the fear of being hacked and suffering impacts on production operations. Thus, the higher the integration level, the more cybersecurity improvement is needed. Based on the insights that have been obtained, the initiatives in developing the vertical integration dimension are summarized into three initiatives as follows:

a. Implementation of Manufacturing Execution System (MES)
b. Implementation of Planning & Scheduling System (APS)
c. Cybersecurity Enhancement

Shop Floor Intelligence and Automation

The main activity of a manufacturing company is to produce goods (Heizer *et al.*, 2017). Thus, having a machine that consistently and optimally produces good-quality products is essential in supporting the business activities of manufacturing companies. The efforts of manufacturing companies to optimize production and product quality have been carried out since the third industrial revolution with the use of robot technology to automate the production process (Oztemel and Gursev, 2020). This effort continues and requires manufacturing companies to develop and integrate implemented automation technology with new technologies that drive the fourth industrial revolution to add more value to their business activities (Frank *et al.*, 2019; Oztemel and Gursev, 2020)

To support improvements in Shop Floor Intelligence and Automation dimensions, industry practitioners suggest that connectivity and communication between machines or PLCs (Programmable Logic Controller) and PLC connectivity with databases through Internet-of-Things (IoT) technology is one of the things needed to be able to improve the current level of readiness of the Shop Floor Intelligence and Automation dimensions.

"The production process system is already digital, using control level such as PLCs, but not yet connected, not yet connected to the database or between PLC itself not yet connected." **Interviewee 1**

"I think the first target is with IoT (Internet-of-Things) because this cannot be separated from that (Industry 4.0)." **Interviewee 3**

Machine-to-machine communication (M2M) refers to direct communication between devices through various media, either wired or wireless, allowing machines to interact (Frank *et al.*, 2019; Oztemel and Gursev, 2020). In the context of Industry 4.0, M2M is considered one of the important components that can improve operational efficiency, quality control, and decision-making (Oztemel and Gursev, 2020). Other research related to M2M was conducted by Ranjan and Hussain (2016), who tried to integrate M2M with Internet-of-Things (IoT). IoT technology as one of the fundamental technologies in the context of Industry 4.0 has been widely mentioned in several studies, such as Bigliardi et al. (2022), Keshav Kolla et al. (2022), and Peter et al. (2022). In the context of the food industry, IoT technology has been used to help improve food safety standards, reduce food waste, reduce yield variation, and monitor product quality (Bigliardi *et al.*, 2022)

Once the connectivity between machines and databases is established, industry practitioners suggest that the data obtained will require a large storage infrastructure. On the other hand, to increase the value of data obtained, the implementation of data analytics, including machine learning and artificial intelligence technologies, will be needed. Furthermore, the analyzed data could then be used as insights by the managers in the decision-making process or fed back directly to machines to adjust parameters in the production process automatically.

"Connectivity means internet and data. This means we need infrastructure for storage. The storage could be stored in the IT facility or in the cloud." **Interviewee 1**

"There is also related to infrastructure; it might need facilities to support." **Interviewee 3**

"After we collected the data, it means that there must be something to analyze. To analyze (the data), we use another platform that can do it; we call it machine learning or AI. Machine learning and AI will provide a suggestion or a certain insight." **Interviewee 1**

"There are outputs from AI or machine learning that are only suggestions, whose actions still need people, or some go directly back to the controller." **Interviewee 1**

The capability to handle large amounts of data, perform well-defined analyses, and use it to improve interoperability between machines is one of the things needed to maximize the adoption of Industry 4.0 (Oztemel and Gursev, 2020). Due to the large amount of data, cloud systems will provide a high-efficiency level in storage infrastructure and the necessary analysis tools (Oztemel and Gursev, 2020). Machine Learning (ML) and Artificial Intelligence (AI) technologies have been applied to several areas in manufacturing companies, including predictive maintenance, predictive forecasting, quality assurance inspection, real-time monitoring, and process automation (Elbasheer *et al.*, 2022; Kehayov *et al.*, 2022). Based on the insights that have been obtained, the initiatives in developing the Shop Floor Intelligence and Automation dimensions are summarized into five initiatives as follows:

a. Connecting PLC to Database through IoT
b. Connecting PLC to PLC for Complex Automation
c. Implementation of Big Data Infrastructure
d. Data Analytics with Machine Learning & AI
e. Integrating Machine Learning & AI with PLC

Workforce Learning & Development

Employees can be the greatest barriers or enablers to the success of an organization's digital transformation process. Building the best possible experience for employees is essential. This includes supporting employees to work faster, smarter, and safer through digital technology and preparing talents for future developments (Westerman and Bonnet, 2020). The initiatives suggested by industry practitioners to improve this dimension include designing and conducting internal training or education programs related to Industry 4.0 for the existing employees. The training program can be in the form of improving existing competencies (upskilling) or completely learning new competencies (reskilling).

“The option chosen is to upskill and reskill.” **Interviewee 1**

“The seniors still have to be educated internally, but maybe it takes a long time, maybe longer than if we educate those who have a fairly high education.” **Interviewee 2**

“Most of it through training, training and the introduction of newer technology or production processes.” **Interviewee 3**

As an alternative, if employees are unable to improve their competencies to the expected level, industry practitioners consider that job rotation or role changes could be made to areas with less digital aspects or Industry 4.0. The changes in employee roles or areas would undoubtedly need to be followed by a good partnership with the labor union to avoid resistance and unintended effects on the company.

“If it is impossible to gain digital knowledge, it can be transferred to another one (job role or area). Rotation is possible.” **Interviewee 2**

“At least I expect no one to be laid off; everything is growing, and there is no employee reduction because of that problem (digital or Industry 4.0).” **Interviewee 2**

“When we want to do upgrading or upskilling, if they are uncomfortable, their actions are not moving forward, but go to the union to refuse, oppose, or resist; it will be an inhibiting factor.” **Interviewee 1**

In the long term, the qualification of new employees should be adjusted to support Industry 4.0 adoption. Competencies relevant to Industry 4.0 can be added as additional so that new employees can quickly adapt to Industry 4.0 implementation programs run by the company.

“The plan is to increase the qualifications for special operators, so it is not in high school anymore, at least in associate degree, so that later we can train them, get other knowledge, and be able to absorb.” **Interviewee 2**

Regarding the human resources aspect, Romanello and Veglio (2022) assessed that the adoption of Industry 4.0 will affect the hiring process of new employees, including the need for new skills, current job positions, and training programs that target upskilling or reskilling employees. Tay et al. (2021) also revealed that companies tend to recruit new employees with more appropriate qualifications and conduct training programs for employees to encourage the adoption of Industry

4.0. Based on the insights, the initiatives in developing the Workforce Learning & Development dimension are summarized into four initiatives as follows:

a. Upskilling & Reskilling for Existing Employees
b. Partnership with Labor Union for Job Role Changes
c. Job Rotation for Existing Employees
d. Adjust Qualification for New Employees

Conceptual Roadmap for Improving Industry 4.0 Readiness

From a strategy and technology perspective, the transition to Industry 4.0 requires a comprehensive strategic roadmap to visualize each step towards a digital manufacturing company (Sarvari *et al.*, 2018). Roadmapping is an important method that has become part of creating and developing strategies and innovations in various companies (Ghobakhloo, 2018). Based on the discussion in the previous section, this research proposes a roadmap to improve the readiness level of Industry 4.0 in the food and beverage industry. The proposed roadmap is depicted in Figure 4. The roadmap is built based on the prioritized dimensions from the quantitative phase. Those dimensions are Vertical Integration for the Process area, Shop Floor Intelligence and Automation for the Technology area, and Workforce Learning & Development for the Organization area.

The current Industry 4.0 readiness level for each prioritized dimension is used as a starting point for the roadmap. Meanwhile, the Industry 4.0 readiness level of the best-in-class global companies acts as the milestone of the roadmap. In order to achieve the milestone, the initiatives that have been identified in the qualitative phase are mapped as a reference for the industry practitioners. The strategic planning horizon chosen by the participating company becomes the timeline in the roadmap. Improvement in top priority KPIs for the food and beverage industry, divided into Productivity and Quality categories, is expected when the roadmap is well executed.

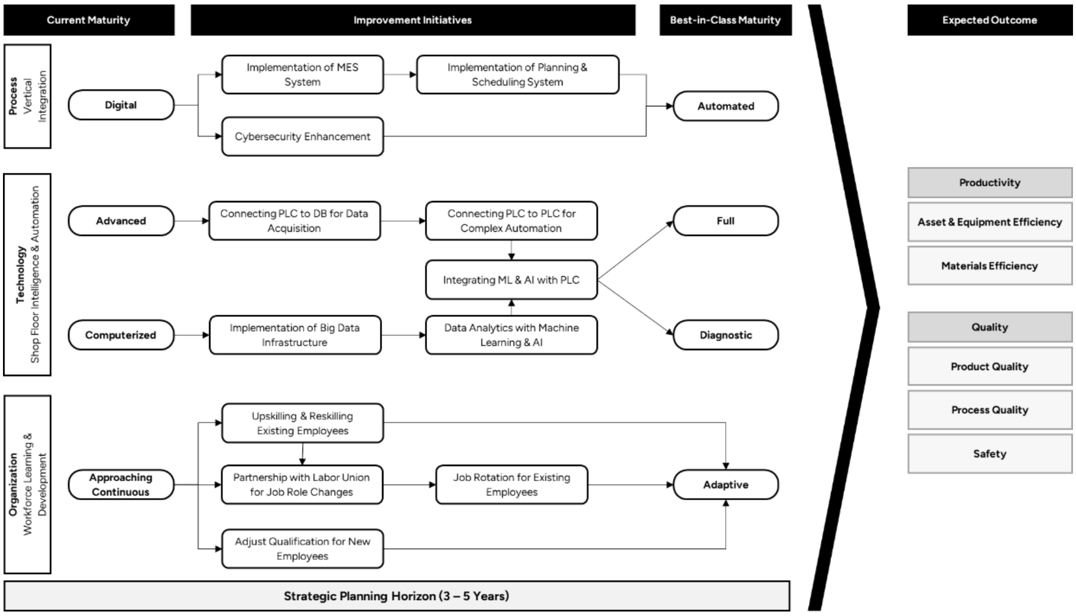

Figure 4 – Conceptual Roadmap for Improving Industry 4.0 Readiness in F&B Industry
Source(s): *(Authors own elaborations, 2024)*

CONCLUSION

Implications for the organization

This study explored the current readiness level of Industry 4.0 implementation in food and beverage manufacturing enterprises in Indonesia with its influencing factors, including the driving forces and barriers to adopting Industry 4.0. With this information, industry practitioners can better plan to exploit the driving forces as well as solve the barriers that potentially arise during the adoption of Industry 4.0. Furthermore, this study also reveals four priority dimensions to be improved. By identifying those dimensions, the organization will have a better focus on allocating its resources. Meanwhile, the government will have a clear direction to provide incentives for manufacturing companies according to what is needed and has the most significant impact on the adoption of Industry 4.0 so that the regional and global goals of the Indonesian government can be achieved. Developing a roadmap with systematic steps, as demonstrated by this study, can be applied so companies have a more precise direction in their Industry 4.0 implementation efforts and achieve the expected potential benefits.

Conclusion and further work

Industry 4.0 implementation in Indonesia's food and beverage manufacturing enterprises is ongoing and is expected to provide benefits, especially in the company's business performance. Based on the Smart Industry Readiness Index framework, the readiness index for Indonesian food and beverage companies is greater than the global average but far behind global companies in the best-in-class category. The lagging behind is influenced by several factors, such as the need for changes in mindset and ways of working, lack of competence from current employees, high investment in adopting new technology, and specific characteristics that become particular aspects of the food and beverage industry. Continuous efforts must be carried out to develop the readiness level of Industry 4.0 to achieve the expected benefits and improve the company's performance, especially in the productivity and quality aspects. The improvement initiatives can be focused on dimensions with the highest impact on improving company performance indicators and approaching the level of readiness of best-in-class global companies. There is a need for cooperation between the university and the government to promote and increase the participation of manufacturing enterprises in research related to Industry 4.0 to create a triple-helix approach to develop the manufacturing industry. The themes generated during qualitative analysis can be explored as further research directions, such as the participation of companies in the Global Lighthouse Network initiative. Many studies related to the level of readiness or maturity of Industry 4.0 still focus on developing dimensions that need to be measured. Applying global frameworks that are practically adopted by industry can enrich empirical research focusing on the sustainable journey of readiness or maturity levels.

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