Modelling Dimensions and Indicators of Readiness for Lean 4.0 Implementation in Indonesian Industries

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Abstract—**The integration of Lean Manufacturing and Industry 4.0, known as Lean 4.0, has emerged as a strategic approach to enhancing operational efficiency, digital transformation, and competitiveness in modern industries. The rapid development of Industry 4.0 has driven a massive transformation in the global manufacturing sector, including Indonesia, which continues to face competitiveness challenges due to limitations in technological capabilities, human resources, and organizational culture. However, the successful implementation of Lean 4.0 requires a structured and measurable level of organizational readiness. This study aims to model the key dimensions and indicators that define the readiness of Indonesian companies for Lean 4.0 implementation. Using a mixed-methods approach of qualitative and quantitative analysis, this study begins with a meta-synthesis of existing literature and expert interviews to identify initial dimensions and indicators, followed by a structured survey to validate the model. The analytical framework integrates the theoretical foundations of Lean and Industry 4.0 principles, existing readiness assessment models, as well as models from key references. The key finding is a proposed model for Lean 4.0 Readiness for Indonesian industries, consisting of 6 key dimensions and 41 indicators. The 6 key dimensions are: Leadership and Strategy, People and Culture, Technology and Digital Infrastructure, Operation and Process, Product and Service, and External Collaboration and Integration. Expert validation and pilot testing confirmed the consistency and contextual relevance of this model for industries in Indonesia. The finding contributes to theory and practice by providing a comprehensive and diagnostic framework for evaluating Lean 4.0 implementation readiness, as well as supporting the development of a readiness model that can be adapted to another industrial park in Indonesia.**

Keywords—Lean 4.0; Industry 4.0; readiness assessment; organizational readiness; Indonesian industries; digital transformation

I. Introduction

The rapid advancement of Industry 4.0 has significantly transformed manufacturing and service industries worldwide. By integrating smart technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), big data analytics, and automation, Industry 4.0 enhances operational efficiency and competitiveness [1]. While Lean 4.0 offers significant benefits, challenges include high implementation costs, workforce skill gaps, and integration complexities. Future trends indicate a growing focus on sustainability within Lean-Industry 4.0 integration, emphasizing the need for further research to address challenges and explore scalable solutions across diverse industrial contexts [2].

Lean Manufacturing has long been recognized as a systematic approach to eliminating waste, improving productivity, and optimizing processes [3]. The convergence of these two concepts, known as Lean 4.0, leverages digital technologies to enhance lean principles, enabling real-time decision-making, predictive maintenance, and adaptive production systems [4]. Industry 4.0 technologies strongly support the Just-in-time and *Jidoka* principles, but have a limited impact on lean waste reduction and teamwork aspects [5].

Currently, the integration model of Lean manufacturing principles and Industry 4.0 has not been found in Indonesia. Previous research has not discussed the external dimension of collaboration, i.e., the relationship between companies and suppliers or customers. Therefore, this study aims to provide a practical assessment model that helps businesses evaluate their readiness and develop strategies for implementing Lean 4.0. Additionally, this research contributes to academic knowledge by bridging the gap between Lean Manufacturing and Industry 4.0 readiness studies, offering a structured framework applicable to emerging economies.

A. Background

The Indonesian manufacturing sector, as a prime mover of the country's economy, contributes around 19% to GDP in 2023 and serves as a major source of employment, export revenue, and industrial growth [6]. Despite its strength in domestic market size, UNIDO's Competitive Industrial Performance Index indicates that Indonesia ranks lower than regional leaders such as China, Thailand, and Vietnam, in terms of manufacturing value added, export complexity, and innovation [7]. The World Economic Forum (WEF) data shows gaps in innovation capacity, infrastructure quality, and technological adoption [8]. In order to improve the competitiveness of industries in Indonesia, the implementation of Lean 4.0 is a necessity.

Despite the potential benefits of Lean 4.0, the successful implementation of Lean 4.0 requires organizations to assess their readiness across multiple dimensions. Many companies, particularly in developing economies like Indonesia, face significant challenges in implementing Lean 4.0 [9]. Issues such as limitations of technology and infrastructure, human resources and skills, leadership commitment, and complexity of integration can hinder the transition. As a result, assessing organizational readiness becomes a crucial step before adopting Lean 4.0. Without proper preparation, companies may face challenges in implementation, leading to inefficiencies and resistance to change. A structured readiness assessment framework can help companies identify strengths, weaknesses, and necessary improvements to ensure a smooth transformation.

While numerous studies have explored the adoption of Industry 4.0 and Lean Manufacturing principles, there is a lack of a comprehensive model for assessing Lean 4.0 readiness, particularly in Indonesian companies. Most existing frameworks focus solely on either technological maturity or lean implementation, failing to provide a holistic approach that considers strategic, workforce, and sustainability factors. To address this gap, this study aims to develop a conceptual model for assessing Lean 4.0 readiness by identifying key dimensions and indicators relevant to Indonesian industries. Specifically, the study seeks to: 1) identify critical dimensions that determine Lean 4.0 readiness, 2) establish key indicators for measuring organizational readiness, and 3) propose a structured model that companies can use for self-assessment and improvement planning.

B. Literature Review

Two models of Lean 4.0 readiness used as the main references in this study are the Lean 4.0 Readiness Assessment Tool and the Dimensions for Lean-Green 4.0 Readiness. These are complemented by references to two broader Industry 4.0 readiness frameworks—one offering an evaluation approach, and another synthesizing dimensions from existing readiness models.

Rahmatindar et al. (2024) [10] proposed a Lean 4.0 Readiness Assessment Tool comprising 5 dimensions and 69 indicators. This model, a modification of the Indonesia Industry 4.0 Readiness Index [INDI 4.0], integrates the Lean Assessment Tool and Industry 4.0 Readiness Assessment Tool. The tool has developed under the conditions of companies in Indonesia. Those dimensions include management and organization, people and culture, products and services, technology, and factory operations. The indicators were validated using the Delphi method, which was carried out in two stages.

Duarte et al. (2025) [11] proposed a baseline framework for designing an assessment model to implement Lean-Green management in an Industry 4.0 environment. This study employed a systematic literature review to investigate the existing literature on Lean, Green, and Industry 4.0. The model consisted of 8 dimensions, namely leadership and strategy, people, process, product, customer, supplier, technology, and governance. It identified 44 indicators (measurement items), which consist of 8 in leadership and strategy, 5 indicators in people, 4 indicators in product, 8 indicators in process, 3 indicators in customer, 5 indicators in supplier, 6 indicators in technology, and 5 indicators in governance.

Wankhede et al. (2022) [12] developed a model for assessing Industry 4.0 readiness in organizations, which comprises 6 criteria (dimensions) and 50 factors (indicators). Various Industry 4.0 Readiness Dimensions and Indicators were obtained from an extensive literature review and finalized using expert opinion. Those dimensions covered technology, organization and management, process, legislation, product, and employee. The model has been tested concerning automotive component manufacturing organizations, and hence, the inferences derived have practical relevance.

To be able for organizations to self-assess their Industry 4.0 readiness to survive and thrive in the age of the Fourth Industrial Revolution, the conceptualization of an Industry 4.0 readiness model with the fundamental model dimensions is needed. Hanafiah et al. (2020) [13] identify 30 Industry 4.0 readiness models with 158 unique model dimensions, by using a systematic literature review (SLR) methodology. Two theoretical contributions of this study are: 6 dimensions (technology, people, strategy, leadership, process, and innovation) that can be considered the most important dimensions for organizations, and 70 (44%) out of a total of 158 unique dimensions for organizations on Industry 4.0 related to the assessment of technology only.

II. RESEARCH METHODOLOGY

A. Research Design

This study employs a mixed-methods research approach to develop and validate a model for assessing Lean 4.0 readiness in Indonesian companies. The research is conducted in two phases:

- Qualitative Analysis – A meta-synthesis and expert interviews to identify key dimensions and indicators of Lean 4.0 readiness.
- Quantitative Analysis – A survey-based study to validate the proposed model and assess its applicability in Indonesian industries.

To develop an analytical framework based on the literature review of dimensions and indicators of readiness for Lean 4.0 implementation, two initial steps of meta-synthesis are undertaken. The first step is to determine and study research topics related to understanding Lean 4.0, readiness assessment in organizational transformation, and the dimensions of Lean 4.0 readiness implementation, as well as its indicators. The result is then summarized. This process involves keyword identification through a search for relevant literature in the database on the website.

In order to support the successful implementation of Lean 4.0 in a company, it is necessary to determine the company's readiness to implement Lean 4.0. The assessment to determine company readiness is designed by combining Lean manufacturing principles and Industry 4.0 technology. An analytical framework model in this study is proposed as described in Fig. 1.

The next step is selecting particular topics using the previous keywords as guidance, which lasted until January 2025. Most of the publications were obtained from academic sources, including journals, conference papers, institutional reports, and dissertations.

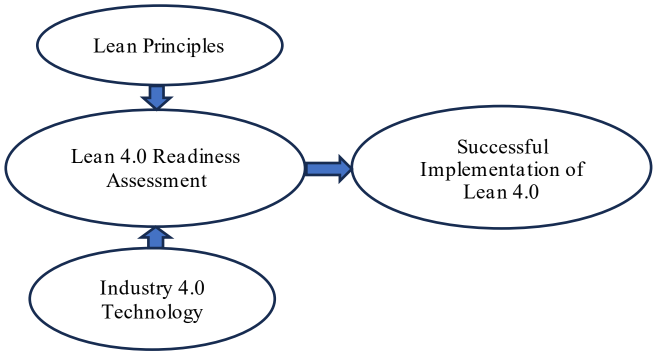

Fig. 1. Analytical framework for Lean 4.0 implementation.

B. Data Collection Methods

1) Meta synthesis: A meta-synthesis of existing studies on Lean 4.0, Industry 4.0, and readiness assessment models is conducted. Academic sources, including journal articles, conference papers, and case studies, are analyzed to identify potential dimensions and indicators relevant to Lean 4.0 readiness.

2) Expert interviews: To validate the findings from the meta-synthesis, semi-structured interviews are conducted with industry experts, Lean practitioners, and academics specializing in Lean 4.0. The key objectives of these interviews are:

- To identify additional readiness factors relevant to Indonesian companies.
- To refine and contextualize the dimensions and indicators based on real-world experiences.

A purposive sampling method is used to select 10–15 experts from the manufacturing, service, and consulting sectors who are involved in implementing Lean 4.0.

3) Survey-based data collection: Based on the identified dimensions and indicators, a structured survey has been designed. The survey consists of Likert-scale questions (1–5) that measure the importance and presence of each indicator within Indonesian companies.

4) Model development and validation: Based on the literature review, expert input, and survey findings, a Lean 4.0 Readiness Model has been developed. The model is validated through:

- Expert review: Feedback from industry professionals and academics.
- Pilot testing: Testing the model on a small group of companies before full implementation.
- Comparative analysis: Benchmarking the model against existing readiness frameworks.

The identified dimensions and indicators are used to develop a Lean 4.0 Readiness Model, which provides a structured framework for assessing an organization's readiness. The model consists of:

- A multi-dimensional assessment framework categorizing companies as "Not ready", "Low readiness", "Moderate readiness", and "Excellent readiness".
- Weighting of indicators based on expert input and survey validation.
- A scoring system to quantify readiness levels across different industries in Indonesia.
  - 4.1–5.0: Excellent readiness – the organization is highly prepared for Lean 4.0.
  - 3.1–4.0: Moderate readiness – some areas need improvement.
  - 2.1–3.0: Low readiness – significant gaps exist.
  - 1.0–2.0: Not ready – foundational work is needed before implementing Lean 4.0.

III. Analytical Framework

A. Overview of Lean 4.0: Integration of Lean Principles and Industry 4.0

Lean Manufacturing, which originated from the Toyota Production System, has long been recognized as a systematic approach to eliminating waste, improving efficiency, and optimizing production processes [14]. Its core principles — such as Just-in-Time (JIT), value stream mapping, and continuous improvement (*kaizen*) — have helped organizations enhance productivity and reduce operational inefficiencies. However, with the emergence of Industry 4.0, these traditional lean practices are being augmented with digital technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), cyber-physical systems, and big data analytics [15]. Industry 4.0 enables real-time data collection, monitoring, and analysis, which supports data-driven decision-making, predictive maintenance, and automation — elements that complement Lean's objectives of operational efficiency and waste reduction [16]. For example, digital *kanban* systems can improve inventory control, while AI-powered analytics can enhance root cause analysis during quality improvement initiatives. This digital transformation led to what is now known as Lean 4.0 [17].

Several studies emphasize that the integration of Lean and Industry 4.0 is mutually reinforcing. While Lean offers a cultural and managerial foundation for operational excellence, Industry 4.0 brings the technological capabilities to execute those principles more efficiently and with greater agility [18]. This synergy allows companies to achieve smart, flexible, and efficient production systems. However, the success of this integration depends on factors such as leadership support, workforce competence, and organizational culture [19].

Despite the promising benefits, organizations must carefully manage the integration process to avoid conflicts between traditional Lean practices and the complexities introduced by advanced technologies. Research highlights the need for a strategic roadmap and an assessment of organizational readiness before adopting Lean 4.0 [20]. Companies must evaluate their readiness and maturity levels in both Lean and digital capabilities, ensuring alignment between technological investments and Lean objectives.

B. Readiness Assessment Frameworks in Industry 4.0 and Lean 4.0

Two main types of Lean 4.0 assessment tools are used to evaluate organizational readiness and maturity in implementing Lean 4.0. Lean maturity assessment models assess an organization's current level of lean implementation, identifying areas for improvement. In contrast, lean readiness assessment models assess an organization's readiness for adopting lean principles and practices. Both are essential for a successful lean transformation, but they apply at different stages and serve different purposes.

A Maturity Assessment Tool for Lean 4.0 Implementation is a structured evaluative framework used to measure the current maturity level of an organization's processes, systems, and capabilities in adopting Lean 4.0. This tool helps organizations determine their progress in their digital Lean transformation process by assessing multiple dimensions. Each dimension is usually rated on a maturity scale, providing a diagnostic snapshot of the organization's progress and highlighting areas that need improvement. It is often used after some lean implementation to track progress and identify areas for further development.

The Lean 4.0 Readiness Assessment Tool is a structured instrument designed to evaluate an organization's readiness for implementing Lean 4.0, which involves integrating Lean manufacturing principles with Industry 4.0 technologies. This tool helps organizations identify their strengths, weaknesses, and gaps across key dimensions. The ultimate goal of the Lean 4.0 Readiness Assessment Tool is to facilitate a smooth and effective transition toward a smart, efficient, and sustainable manufacturing system aligned with Industry 4.0 paradigms. This tool is typically conducted before implementing Lean 4.0 to increase the probability of success. Table I shows lean readiness and maturity models, which were adopted from [21].

TABLE I. THE EXISTING LEAN READINESS AND MATURITY ASSESSMENT MODELS

Assessment	Developer	Dimensions
Lean Enterprise Self-Assessment Tool (LESAT)	LAI-MIT (2001)	Strategic cycle, planning cycle, and execution cycle
Renault Production System (RPS) Rocket	SPR (2004)	Operational stability (base), continuous flow and efficiency (body), innovation and excellence (nose), and people and culture (propulsion system)
The Shingo Prize Model	Utah State University (1988)	Cultural enablers, continuous improvement, and enterprise alignment
Capgemini lean model	Capgemini (2005)	Process, people, and organization
Lean capability model	Jorgensen et al. (2007)	Technical perspective, organizational perspective
Logical model of lean assessment	Hines (2011)	Strategic deployment, value stream management, people, application of lean tools and techniques, and extended enterprise
The Digital Green Lean (DGL) Maturity Model	Gatell and Avella (2024)	Digital lean business culture (values and principles, customer centricity, and operational excellence) and digital lean leadership (customer orientation, personal development, lean principles, and performance orientation)

Source: Adopted from Setianto & Haddud (2016), [21]

The frameworks for Industry 4.0 maturity and readiness are shown in Table II. Organizational readiness refers to the extent to which a company possesses the capabilities, resources, and strategic alignment necessary to adopt new technologies or operational models [22]. Several readiness assessment frameworks have been developed for Industry 4.0 adoption, but few studies have focused on a structured model specifically tailored to Lean 4.0 [23], [24]. Existing frameworks primarily evaluate technological maturity and digital infrastructure, often neglecting critical factors such as leadership commitment, workforce skills, and sustainability considerations.

For instance, the Smart Industry Readiness Index (SIRI) developed in Singapore evaluates readiness across *Process, Technology,* and *Organization* dimensions, emphasizing the role of advanced digital infrastructure and automation. Similarly, the IMPULS Industry 4.0 Readiness Model from Germany highlights technological maturity and innovation-driven strategy as core enablers of transformation. Although these models provide strong analytical frameworks for industrial digitalization, they often assume high baseline technological capacity, making them less applicable to small and medium-sized enterprises (SMEs) in emerging economies.

In the context of Indonesia, despite governmental efforts through Making Indonesia 4.0 and the INDI 4.0 Index, many firms remain at an early stage of readiness. Studies indicate that barriers include limited digital infrastructure, insufficient managerial commitment, and a lack of workforce upskilling programs. This highlights the necessity for a comprehensive, adaptive readiness model—one that not only aligns with global Lean 4.0 frameworks but also incorporates contextual factors such as leadership strategy, people and culture, and external collaboration.

Recent studies emphasize the need for multidimensional readiness models that incorporate both technological and organizational factors. For instance, recent studies emphasize the need for multidimensional readiness models that incorporate both technological and organizational factors. For instance, Kumar et al. (2020) [26] propose a readiness framework that integrates strategy, workforce capability, and process optimization. The study suggests that an effective Lean 4.0 readiness model must extend beyond technology, encompassing elements such as leadership, workforce skills, data-driven decision-making, and environmental sustainability.

TABLE II. THE EXISTING FRAMEWORKS FOR INDUSTRY 4.0 MATURITY AND READINESS

Name of the model	Developer	Dimensions
IMPULS – Industry 4.0 Readiness	Lichtblau et al. (2015)	Strategy and organization, smart factory, smart operations, smart products, data-driven services, and employees
SIMMI 4.0	Leyh et al. (2016)	Vertical integration, horizontal integration, digital product, and cross-sectional technology
Industry 4.0 / Digital Operation Self-Assessment	Price Waterhouse Coopers (2016)	Digital business and customer access, digitization of products / services, data analytics, IT infrastructure, IT architecture, security, and digital culture
Industry 4.0 readiness and maturity of manufacturing enterprises (Industry 4.0 MR)	Schumacher et al. (2016)	Products, customers, operations and technology, strategy, leadership, governance, culture, and people
Industry 4.0 readiness model (WMG)	Warwick University	Products and services, manufacturing and operations, strategy and organization, supply chain, business model, legal considerations
Industry 4.0 - MM	Gokalp et al. (2017)	IT, data governance, information flow, process transformation, and organizational structure / strategy
Digital Readiness Assessment Maturity Model (DREAMY)	De Carolis et al. (2017]	Process, monitoring and control, technology, and organization
Maturity and Readiness Model for Industry 4.0 Strategy	Akdil et al. (2018)	Smart products and services, smart business processes, strategy, and organization
Indonesia Industry 4.0 Readiness Index (INDI 4.0)	Indonesian Ministry of Industry (2018)	Management and organization, people and culture, product and services, technology, and factory operation
Industry 4.0 Maturity model	Sony et al. (2019)	Employee, level of digitalization, extent of digitalization, organizational strategy, top management involvement
360 Digital Maturity Assessment	Colli et al. (2019)	Governance, technology, value creation, connectivity, competence
The Smart Industry Readiness Index (SIRI)	EDB of Singapore	Technology (automation, connectivity, intelligence), process (operation, supply chain, product lifecycle), and organization (talent readiness, structure, and management)
Industry 4.0 Readiness Model	Hanafiah, Soomro, and Abdullah (2020)	Technology, people, strategy, leadership, process, and innovation
Industry 4.0 MR	Kumar and Akhilesh (2021)	Strategy, organization, business model, employee, manufacturing and operations, supply chain, production system, products, and services

Source: Fauskanger et al. (2023), [25] and Rahmatindar et al. (2024), [10]

C. Main References of Lean 4.0 Readiness Model

Organizational transformation — particularly when driven by digitalization or process innovations like Lean 4.0 — requires a systematic evaluation of readiness to ensure effective implementation and sustainable outcomes. A readiness assessment functions as a diagnostic mechanism to gauge an organization's capability, willingness, and preparedness for change. It helps determine whether essential foundations such as strategy, leadership, culture, and resources are properly aligned to support transformation initiatives.

Preparation models have gained significant attention in the context of digital transformation and Industry 4.0. For example, Schumacher et al. (2016) [23] proposed a maturity model to assess readiness across dimensions such as strategy, culture, IT infrastructure, and operations. Similarly, Mittal et al. (2018) [24] emphasized that small and medium-sized enterprises (SMEs) need to consider their technological capabilities, human resources, and leadership support before initiating smart manufacturing initiatives.

When it comes to Lean transformation, readiness assessment also plays a critical role. Antony et al. (2017) [27] pointed out that a lack of readiness, particularly in areas such as employee engagement, continuous improvement culture, and management commitment, can hinder Lean adoption. Integrating Lean with Industry 4.0 (i.e., Lean 4.0) introduces additional complexity, making readiness assessment even more vital.

Several frameworks have been developed to assess transformation readiness across various industries. Some studies have identified the dimensions and indicators of readiness for Lean 4.0 implementation using the SLR approach. Therefore, this approach was not used in this study. Common dimensions include Leadership and Strategic Alignment, Workforce Competency and Culture, Technological Infrastructure, Process Maturity, and Data-driven Decision-making. These dimensions often serve as the basis for constructing indicators and metrics that help companies identify gaps and prioritize areas for improvement before full-scale implementation.

IV. MODELLING LEAN 4.0 READINESS DIMENSIONS AND INDICATORS

Based on the readiness models used as the primary references, certain dimensions were identified by the experts involved in this study. The selected dimensions were then used to assign the conceptual framework, as described in Fig. 2.

The convergence between Lean Manufacturing and Industry 4.0—commonly termed Lean 4.0—has become a significant topic in industrial transformation research. Lean Manufacturing focuses on process efficiency, waste reduction, and continuous improvement, while Industry 4.0 emphasizes automation, data-driven decision-making, and cyber-physical integration. The synergy between these two paradigms enables both operational excellence and digital competitiveness. However, while advanced economies have developed mature readiness models to support digital transformation, many developing countries still face difficulties in adopting such frameworks due to contextual and infrastructural limitations.

From the selected dimensions, indicators were then identified for each dimension, based on the reference model, as well as other relevant papers or studies on the same topic. These indicators are supported by several references that mention them in their studies. It is shown in Table III.

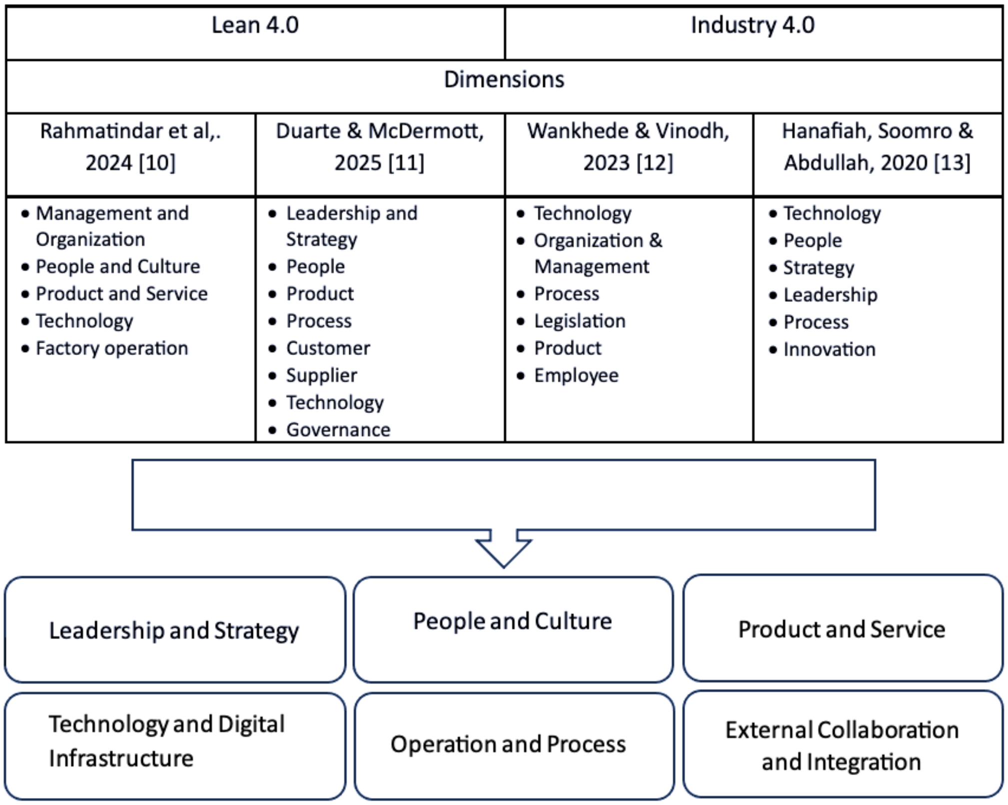

Fig. 2. The proposed dimensions used to assign the conceptual framework (adopted from [11]).

TABLE III. DIMENSIONS AND INDICATORS OF THE READINESS MODEL FOR LEAN 4.0 ADOPTION

Lean 4.0 Dimension	Indicators	Reference
Leadership and Strategy Heming *et al*. (2019), [31] Leong *et al*. (2019), [33] Letchumanan *et al*. (2022), [34] Hanafiah *et al*. (2020), [13]	Management support for Lean 4.0 transformation	[10], [13], [19], [23], [28], [29], [30], [31], [32], [34], [43]
	Commitment to active management involvement	[10], [12], [13], [15], [19], [28], [29], [30], [34], [35] [36], [37]
	Clear digital transformation vision, roadmap, and alignment with mission	[11], [12], [19], [23], [28], [29], [31], [33], [34], [38], [39], [40], [43]
	Long-term investment strategies (human, financial, and technological)	[10], [11], [12], [29], [40], [43]
	Dedicated Lean 4.0 transformation teams / Governance structure to oversee the transformation	[10], [11], [23], [29]
	Management standards, governance, and legal compliance	[11], [28], [37], [47]
	Adapt a new strategy / new business model*	[11], [19], [23], [34], [41], [42]
	Funds' availability / Financial resources*	[19], [34], [38]
	Communication and change management*	[10], [19], [28], [31]
People and Culture Nizam-Hanafiah, Soomro & Abdullah (2020), [13]	Employee skills and qualifications (Lean and Industry 4.0)*	[11], [12], [13], [19], [23], [33], [34], [37], [38], [40], [42], [43], [44], [45], [46], [47]
	Employee openness to digital transformation and continuous improvement*	[11], [12], [23], [38], [43]
	Systematic problem-solving to improve digital transformation	[11], [12], [24], [23], [30], [37], [42], [45], [48]
	The existence of structured training / workshops / certifications for Lean 4.0	[10], [11], [12], [13], [33], [34], [37], [38], [39], [40], [42], [44], [45], [46], [47]
	Employee involvement and empowerment*	[13], [33], [34], [37], [40], [46], [47]
	Culture and supportive ambiance*	[13], [34], [44]
Technology and Digital Infrastructure	Machine-to-machine (M2M]) connectivity and transparency in data flow	[10], [12], [23], [38], [42], [43], [49]
	Connectivity of systems within the company across different technical disciplines	[10]; [43], [50]

	Implementation of the Internet of Things (IoT) / Implementation of industrial automation (IoT, ERP, RFID, SCADA, PLC)	[10]; [12], [13], [40], [51]
	Conversion of manual processes to digital	[10]; [19], [43], [52], [53], [54]
	Cybersecurity implementation and training	[10]; [19]
	Implementation of big data and cloud computing*	[13], [19], [38], [40], [55], [56], [57]
	Technology for information exchange*	[13], [38]
Operation and Process	Implementation of Lean tools: First In First Out (FIFO), Just in Time (JIT), Plan-Do-Check-Act (PDCA), etc.	[10], [28], [46], [47]
	Standardization of supply chain / logistic flow / Supply chain activities improvement	[10], [37],
	Use of digital technologies in operation: automation, real-time monitoring, and Overall Equipment Effectiveness (OEE)	[10], [13], [19], [38], [43]
	The existence of performance indicators for automated processes impact on factory operations	[10]
	Real-time monitoring and control	[23], [31], [34], [37], [38], [39], [44], [45]
	Maintenance types: predictive, preventive, and corrective	[10], [43]
	Digital storage of operational data / cloud solution	[10], [34], [38], [43], [55]; [57]
	Interdepartmental collaboration*	[23]
Product and Service	Availability of product information systems for vendors / customers	[10], [12], [43]
	Data analysis from customers, business partners, and vendors	[10]
	Customer feedback mechanisms and satisfaction monitoring	[10], [43]
	Use of big data for product / service improvement	[10], [38]
	Integration of products with digital technologies	[10], [11], [12], [23], [38], [43]
External Collaboration and Integration	Use of digital channels with suppliers / customers	[11], [19], [23], [34], [38]
	Knowledge sharing and uncertainty management across companies	[11], [37], [45], [58]
	Customer involvement to lead Lean 4.0 implementation	[38], [40]
	Supplier integration and collaboration*	[11], [24], [28], [37], [38], [40], [46], [47]
	A balance between environmental, economic, and social needs for sustainability*	[19]

The results of the identification suggest that there are six (6) selected dimensions and forty-one (41) indicators. There are nine indicators for the Leadership and Strategy dimension. Three of these indicators, notably new strategy / new business, fund availability, and communication and change management, fall outside of the primary references.

For the People and Culture dimension, there are six indicators, two of which are from sources outside the main references. These indicators include employee participation and empowerment, as well as a supportive culture and environment. Technology and Digital Infrastructure have three indicators, the most important of which are big data and cloud computing implementation and information exchange technology.

All five indicators in the Product and Service dimension come from the main reference. The last dimension, External Integration, is an additional dimension that accommodates several indicators also mentioned in the main references. Two of the five indicators not mentioned in the main reference in this dimension are supplier integration and collaboration, as well as a balance between environmental, economic, and social needs for sustainability.

To supplement and refine the above dimensions and indicators, expert validation is required. Expert opinions are obtained from academics, industry professionals, and Lean practitioners. Additionally, pilot testing (in the form of case studies) was conducted, and the findings were used to refine the meta-synthesis framework.

V. Results and Discussion

The study focused on identifying the dimensions and indicators that are important for measuring a company's readiness to implement Lean 4.0 (Lean 4.0 readiness assessment model) based on the assumption that most local companies in Indonesia's Jababeka Industrial Park have not yet implemented Lean 4.0.

Based on input or suggestions from experts, the dimensions and indicators for determining a company's readiness to implement Lean 4.0 as a result of the meta-synthesis are already quite comprehensive and do not need to be added to or reduced. However, they cautioned that the proposed dimensions and indicators are still too sophisticated, especially for small and medium-sized industries. Domestic companies at that level (within the category) generally have not yet implemented or carried out most of the indicators mentioned. Even some large companies seem not to have yet, or are still struggling to apply Lean principles.

Several experts highlight the proposed dimensions based on their level of importance for the successful implementation of Lean 4.0 in companies. They argue that the most important aspect in implementing Lean 4.0 is people and their work culture, because people are the main driving force behind the success of the transformation, even more so than the technology itself. Lean 4.0 is based on changing the mindset and behavior of the people involved in it. From this perspective, what is important at this stage is that their mindset in working is aligned with the Lean 4.0 mindset. Fundamental issues or principles related to customer satisfaction, particularly concerning quality and delivery, must be resolved thoroughly before considering technology.

The dimension of leadership and clear strategy, particularly commitment from top management, are other key aspects. Without strong leadership and commitment, as well as a clear strategy, the transformation to Lean 4.0 in a company will lack direction, support, and sustainability. Leadership provides the driving force, while strategic readiness provides the direction. Additionally, top management must also set a good example to serve as a model for their employees.

Digital technology and infrastructure are the technical foundation of Lean 4.0. With such a large volume of data transactions, processing and analysis must use tools so that the data can be utilized to its fullest potential and used as efficiently as possible. For product service delivery to customers, comprehensive customer data analysis is required. Clear information availability is crucial so that anyone with a stake in the matter (e.g., during shift changes) can immediately know what is needed or what actions must be taken.

The trend toward digitization in manufacturing systems has already begun and is currently underway. It is up to the people (human resources) to decide whether to accept it or not, whether to view it as an opportunity or a threat. This includes top management, who must understand the importance of Lean 4.0 principles.

In order to support the development of research and the application of Lean Manufacturing based on Industry 4.0 technology (Lean 4.0), blockchain technology is one of the key technologies that is very important to adopt in modern manufacturing systems. Blockchain technology plays a significant role in improving the transparency, efficiency, and reliability of information flow throughout the supply chain. By integrating blockchain with IoT technology, AI, digital tracking systems, secure and real-time business process automation, and distributed, immutable data recording, a system can be created that reduces information waste, accelerates decision-making, and reinforces Lean principles such as just-in-time, kaizen, and the elimination of non-value-added activities.

Before the large-scale data collection, a pilot test of the Lean 4.0 readiness questionnaire was conducted to evaluate the clarity, reliability, and validity of the proposed dimensions and indicators. The pilot study involved a sample of 15 respondents, consisting of production managers, lean coordinators, and digital transformation specialists from selected Indonesian manufacturing companies. Respondents were asked to complete the survey and provide feedback on the comprehensibility of each question, the appropriateness of the terminology used, and the overall structure of the survey.

Table IV shows the statistical analysis of the pilot data included reliability testing using Cronbach's alpha for each dimension. All dimensions recorded alpha values above the 0.70 threshold, indicating acceptable internal consistency. However, minor adjustments were made to the wording of certain indicators to enhance clarity and avoid technical ambiguity. Content validity was also strengthened through consultation with three academic experts and two industry practitioners, who reviewed the questionnaire to ensure alignment with Lean 4.0 principles and the Indonesian manufacturing context.

TABLE IV. CRONBACH'S ALPHA RELIABILITY RESULT

Variable	Number of items	Cronbach's Alpha	Criteria	Comment
Leadership and Strategy	9	0.807	0.7	Reliable
People and Culture	6	0.873	0.7	Reliable
Technology and Digital Infrastructure	7	0.895	0.7	Reliable
Operation and Process	8	0.807	0.7	Reliable
Product and Service	5	0.791	0.7	Reliable
External Collaboration and Integration	5	0.784	0.7	Reliable

The feedback and findings from this pilot testing served as a critical input in refining the measurement model. Ambiguous or overlapping items were revised or eliminated, while the sequence of questions was restructured to improve logical flow. As a result, the final instrument was considered robust and contextually relevant, supporting the subsequent empirical phase of readiness modelling for Lean 4.0 implementation. The dimension of Leadership and Strategy is a common dimension identified in various models, focusing on management support, management commitment, clear vision, long-term investment (in human, financial, and technological resources), a Lean team, fund availability, management standards, new business strategies, and communication. Organizations with strong leadership support tend to exhibit higher success rates in digital Lean transformation due to their ability to align organizational goals with digital strategies [20]. Indicators under this dimension typically include the existence of a Lean 4.0 roadmap, leadership involvement, and cross-functional transformation teams [23].

People and Culture is another critical dimension, as the human element plays a central role in adopting and sustaining new technologies and Lean culture. According to [24], digital literacy, lean knowledge, openness to change, and structured training programs are necessary to ensure workforce adaptability. The presence of competency development programs, employee participation in decision-making, and a culture of continuous improvement are key indicators for this dimension.

The dimension of Technology and Digital Infrastructure refers to the availability and integration of enabling technologies such as IoT, ERP systems, RFID, SCADA, big data analytics, cyber-physical systems, and information exchange. Buer et al. (2018) [15] suggest that Lean 4.0 is enhanced by real-time data and automation, which support Lean goals like waste reduction, agility, and responsiveness. Indicators in this dimension include the implementation of digital tools, system connectivity, and cybersecurity measures.

Operation and Process integrate Lean methods (e.g., Just-in-Time, PDCA) with digital systems to enhance process performance. Key indicators include the implementation of Lean tools, the use of digital technologies in operations, standardization of the supply chain, digital storage of operational data, the existence of performance indicators for automated processes in factory operations, as well as monitoring and quality assurance, maintenance, and departmental collaboration.

The Product and Service dimension plays a pivotal role in determining an organization's readiness for Lean 4.0 implementation, particularly in enhancing customer value through data integration, feedback responsiveness, and digital innovation. The indicator 'Availability of product information systems for vendors and customers' reflects an adoption of digital platforms such as product portals, e-catalogs, and customer relationship management (CRM) tools. These systems help improve transparency, minimize information gaps, and accelerate response time—capabilities that strongly support the objectives of Lean 4.0.

The indicator 'data analysis from customers, business partners, and vendors' reflects how firms collect transactional or behavioral data and integrate and jointly analyze these datasets across the supply chain. It increases the ability to gain comprehensive insights and coordinate value stream improvements. The indicator 'Integration of products with digital technologies' demonstrates how some companies are beginning to embed sensors, connectivity modules, and smart features into their products. However, for most firms, particularly SMEs, this integration remains aspirational due to high costs, lack of technical expertise, and limited R&D investment. The indicator 'Use of big data for product/service improvement' shows the data collection at various operational touchpoints, and the capacity to analyze and apply these insights toward product innovation or service refinement. Many firms rely on basic analytics or retrospective reporting, falling short of leveraging predictive analytics or AI-driven decision-making, which are integral to a Lean 4.0 approach [20]. Lastly, the indicator 'Customer feedback mechanisms and satisfaction monitoring' is how companies adopt digital survey tools, post-purchase feedback systems, and service-level monitoring. However, the challenge lies in translating this feedback into rapid, systemic improvements — a key Lean principle that remains underutilized.

The External Collaboration and Integration dimension reflects an organization's ability to build, sustain, and digitally enable relationships with key stakeholders such as suppliers, customers, and business partners. In the context of Lean 4.0, collaboration is no longer limited to operational coordination but extends toward the integration of digital technologies, joint value creation, and sustainability-oriented partnerships. The key indicators include supplier collaboration and integration; use of digital channels with suppliers/customers; knowledge sharing and uncertainty management across companies; customer involvement to lead Lean 4.0 implementation; and a balance between environmental, economic, and social needs for sustainability.

Table V shows a proposed Lean 4.0 Readiness model. Compared to other models for measuring readiness to implement Lean Manufacturing and Industry 4.0, this model is more comprehensive. INDI 4.0, which emphasizes readiness to implement Industry 4.0, consists of five dimensions: Management and Organization, People and Culture, Products and Services, Technology, and Factory and Operations. Rahmatindar's model, which draws on INDI 4.0 as its primary reference, focuses on Lean 4.0. It has the same five dimensions as INDI 4.0, but it includes 69 indicators. The additional dimension in this model is External Collaboration and Integration. This is because in digital transformation, the relationships between industry or companies with suppliers and customers are inevitable.

The dimensions of Management and Organization in this model are slightly different, namely, Leadership and Strategy. The Technology dimension in this model includes Digital Infrastructure. Meanwhile, Factory Operations are referred to as Operation and Process. There are fewer indicators in this model compared to Rahmatindar's, because several indicators have been combined into one; for example, the implementation of IoT, ERP, RFID, SCADA, and PLC has been combined into the implementation of industrial automation.

TABLE V. PROPOSED MODEL OF KEY DIMENSIONS AND INDICATORS FOR LEAN 4.0 READINESS

Dimension	Indicator
Leadership and Strategy	Management support for Lean 4.0 transformation
	Commitment to active management involvement
	Clear digital transformation vision, roadmap, and alignment with mission
	Long-term investment strategies (human, financial, and technological)
	Dedicated Lean 4.0 transformation teams
	Funds' availability
	Management standards, governance, and legal compliance
	New business strategy / model
	Communication and change management
People and Culture	Employee skills and qualifications

Dimension	Indicator
	Employee openness to digital transformation and continuous improvement
	Systematic competency development
	The existence of structured training / workshops / certifications for Lean 4.0
	Employee involvement (decision participation) and empowerment
	Culture and supportive ambiance
Technology and Digital Infrastructure	Implementation of industrial automation (IoT, ERP, RFID, SCADA, PLC)
	Machine-to-machine (M2M) connectivity and transparency in data flow
	Connectivity of systems within the company across different technical disciplines
	Implementation of big data and cloud computing
	Conversion of manual processes to digital
	Technology for information exchange
	Cybersecurity implementation and training
Operation and Process	Implementation of Lean tools: First In First Out (FIFO), Just in Time (JIT), Plan-Do-Check-Act (PDCA)
	Use of digital technologies in operation: automation, real-time monitoring, and Overall Equipment Effectiveness (OEE)
	Standardization of supply chain / logistic flow
	Digital storage of operational data / cloud solution
	The existence of performance indicators for automated processes impact on factory operations
	Continuous monitoring and quality assurance
	Maintenance types: predictive, preventive, and corrective
	Interdepartmental collaboration
Product and Service	Availability of product information systems for vendors / customers
	Data analysis from customers, business partners, and vendors
	Integration of products with digital technologies
	Use of big data for product / service improvement
External Collaboration and Integration	Customer feedback mechanisms and satisfaction monitoring
	Supplier collaboration and integration
	Use of digital channels with suppliers / customers
	Customer involvement to lead Lean 4.0 implementation
	A balance between environmental, economic, and social needs for sustainability

VI. Conclusion

This study has developed and modelled a comprehensive set of dimensions and indicators for assessing organizational readiness for Lean 4.0 implementation, focused on digital transformation. The proposed framework integrates lean principles with Industry 4.0 technologies, emphasizing not only operational efficiency but also digital capability, external collaboration, and sustainability. Through literature review, expert validation, and pilot testing, the model was refined to include dimensions such as product and service readiness, process and technology integration, workforce capability, external collaboration and integration, and leadership and strategic alignment.

Findings indicate that while many organizations demonstrate moderate readiness in areas such as supplier collaboration, digital channel adoption, and basic lean practices, significant gaps remain in advanced digital integration, systematic competency development, and sustainability-driven collaboration. In particular, customer co-creation, data-driven decision-making, and alignment between environmental, economic, and social objectives require further development to fully realize the potential of Lean 4.0.

The readiness model contributes to both theory and practice by offering a structured approach to evaluate an organization's readiness, enabling targeted improvement strategies before full-scale Lean 4.0 deployment. This study will be continued by creating and applying an instrument protocol based on findings in Table V. Empirical data collected from a survey using the instrument is needed in the next work.

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References

[1] Bhanu Prakash Sah, Nadia Islam Tanha, Md Arafat Sikder, and S M Habibullah, "The Integration of Industry 4.0 and Lean Technologies in Manufacturing Industries: A Systematic Literature Review". International

Journal of Management Information Systems and Data Science, vol. 1 no. 3, 2024, pp. 14-25.

[2] Shirin Begum, Sayeda Sufia Sumi, “Strategic Approaches To Lean Manufacturing In Industry 4.0: A Comprehensive Review Study”. Academic Journal On Science, Technology, Engineering & Amp; Mathematics Education, vol. 04 issue 03 (2024): pp. 195-212

[3] L. Naciri, Z. Mouhib, M. Gallab, M. Nali, R. Abbou, A. Kebe, “Lean and industry 4.0: A leading harmony”. Procedia Computer Science, vol. 200, 2022, pp. 394-406, ISSN 1877-0509.

[4] Luana Sposito Valamede & Alessandra Cristina Santos Akkari, “Lean 4.0: A New Holistic Approach for the Integration of Lean Manufacturing Tools and Digital Technologies”. International Journal of Mathematical, Engineering and Management Sciences, vol. 5 no. 5, 2020, pp. 851-868.

[5] Rosin Frédéric, Pascal Forget, Samir Lamouri, and Robert Pellerin, “Impacts of Industry 4.0 Technologies on Lean Principles”. International Journal of Production Research, vol. 58 issue 6, 2020, pp. 1644–1661.

[6] Pusat Statistik (BPS). “Statistical Yearbook of Indonesia 2024”.

[7] United Nations Industrial Development Organization. (UNIDO). “Industrial development report 2023: Industrialization in a digital age”.

[8] World Economic Forum (WEF), “Global Competitiveness Report”, 2023.

[9] Hasbullah, Hasbullah, and Salleh Ahmad Bareduan, “Capturing the Reality of Industry 4.0 Readiness Dimensions and Indicators in a Developing Country: An Analysis of Applying Industry 40 in Indonesia”, The South African Journal of Industrial Engineering, vol. 34 no. 2, 2023, pp. 61-78.

[10] Rahmatindar, P.O, Singgih, M.L, & Karningsih P.D, “Development of Lean 4.0 Readiness Assessment Tool”, Jurnal Teknobisnis, vol. 10 no. 1, 2024, pp. 46-56.

[11] Duarte, S., & Mc Dermott, O., “The dimensions of Lean-Green 4.0 readiness a Systematic literature review”, Production Planning & Control, vol. 36 issue 9, 2025, pp. 1175–1187.

[12] Wankhede, V.A. and Vinodh, S., "Benchmarking Industry 4.0 readiness evaluation using fuzzy approaches", Benchmarking: An International Journal, vol. 30 no. 1, 2023, pp. 281-306.

[13] Hizam-Hanafiah M, Soomro MA, Abdullah NL., “Industry 4.0 Readiness Models: A Systematic Literature Review of Model Dimensions”, Information, vol. 11 no. 7, 2020, pp. 364.

[14] Womack, J. P., & Jones, D. T. (1997), “Lean Thinking - Banish Waste and Create Wealth in your Corporation”. Journal of the Operational Research Society, vol. 48 issue 11, 2017, pp. 1148.

[15] Buer, Sven-Vegard, Jan Ola Strandhagen, and Felix T. S. Chan, “The Link between Industry 4.0 and Lean Manufacturing: Mapping Current Research and Establishing a Research Agenda, ” International Journal of Production Research 56 (8), 2018, pp. 2924–2940.

[16] Dennis Kolberg, Detlef Zühlke, “Lean automation enabled by Industry 4.0 technologies”, IFAC-PapersOnLine, vol. 48 issue 3, 2015, pp. 1870–1875.

[17] Sanders, A., Elangeswaran, C., & Wulfsberg, J. P., “Industry 4.0 implies Lean Manufacturing: Research activities in Industry 4.0 function as enablers for Lean Manufacturing”, Journal of Industrial Engineering and Management, vol. 9 no. 3 10, 2016, pp. 456–482.

[18] Tortorella, Guilherme Luz, and Diego Fettermann, “Implementation of Industry 4.0 and Lean Production in Brazilian Manufacturing Companies, ” International Journal of Production Research 56 (8), 2017, pp. 2975–2987.

[19] Michael Sony, Shubash Naik, “Key factors for the successful implementation of Industry 4.0 in manufacturing organizations”, Technology in Society, vol. 61, 2020, 101248, ISSN 0160-791X.

[20] Rossini, M., Costa, F., Tortorella, G.L. et al., “The interrelation between Industry 4.0 and lean production: an empirical study on European manufacturers”, The International Journal of Advanced Manufacturing Technology, vol. 102, 2019, pp. 3963–3976.

[21] Setianto, P. and Haddud, A., “A maturity assessment of lean development practices in manufacturing industry”, International Journal of Advanced Operations Management (IJAOM), vol. 8 no. 4, 2016, pp. 294–322.

[22] Weiner, B. J. “A theory of organizational readiness for change”. Implementation Science, vol. 4 no. 67, 2009.

[23] Schumacher, A., Erol, S., & Sihn, W., “A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises”, Procedia CIRP, vol. 52, 2016, pp. 161–166.

[24] Mittal, S., Khan, M. A., Romero, D., & Wuest, T., “A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs)”, Journal of Manufacturing Systems, vol. 49, 2018, pp. 194–214.

[25] Fauskanger, E., Fatenni, D. & Powell, D., “Towards an assessment model for Lean and Green 4.0”, Journal of International Doctoral Research, vol. 10 no. 1, 2023.

[26] Kumar, R., Kr. Singh, R., Kr. Dwivedi, Y., “Application of industry 4.0 technologies in SMEs for ethical and sustainable operations: Analysis of challenges”, Journal of Cleaner Production, vol. 275, 2020, 124063, ISSN 0959-6526.

[27] Jiju Antony, Ronald Snee, Roger Hoerl, “Lean Six Sigma: yesterday, today and tomorrow”, International Journal of Quality & Reliability Management, vol. 34 issue 7, 2017, pp. 1073–1093.

[28] Hines P., "How to create and sustain a lean culture", Development and Learning in Organizations: An International Journal, vol. 24 no. 6, 2010.

[29] Khourshed, Nevien Farouk, Sahar Sobhy Elbarky, and Sarah Elgamal, “Investigating the Readiness Factors for Industry 4.0 Implementation for Manufacturing Industry in Egypt”, Sustainability, vol. 15 no. 12, 2023, pp. 9641.

[30] Ananya Bhattacharya, Alka Nand, Pavel Castka, “Lean-green integration and its impact on sustainability performance: A critical review”, Journal of Cleaner Productio, vol. 236, 2019, 117697, ISSN 0959-6526.

[31] Helming, S., F. Ungermann, N. Hierath, N. Stricker, and G. Lanza. “Development of a Training Concept for Leadership 4.0 in Production Environments”. Procedia Manufacturing, vol. 31, 2019, pp. 38–44.

[32] Wagire, Aniruddha Anil, Rohit Joshi, Ajay Pal Singh Rathore, and Rakesh Jain, “Development of Maturity Model for Assessing the Implementation of Industry 4.0: Learning from Theory and Practice”, Production Planning & Control, vol. 32 no. 8, 2020, pp. 603–622.

[33] Leong, W.D., Lam, H.L., Ng, W.P.Q. et al., “Lean and Green Manufacturing— a Review on its Applications and Impacts”, Process Integration and Optimization of Sustainability, vol. 3, 2019, pp. 5–23.

[34] Letchumanan, L. Thiruvarasu, Hamed Gholami, Noordin Mohd Yusof, Nor Hasrul Akhmal Bin Ngadiman, Anas A. Salameh, Dalia Štreimikienė, and Fausto Cavallaro, “Analyzing the Factors Enabling Green Lean Six Sigma Implementation in the Industry 4.0 Era”, Sustainability, vol. 14 no. 6, 2022, pp. 3450.

[35] Schmidt, R., Möhring, M., Härting, RC., Reichstein, C., Neumaier, P., Jozinović, P., “Industry 4.0 - Potentials for Creating Smart Products: Empirical Research Results. In: Abramowicz, W. (eds) Business Information Systems”, BIS 2015. Lecture Notes in Business Information Processing, vol. 208, 2015, Springer, Cham.

[36] S. Shamim, S. Cang, H. Yu and Y. Li, "Management approaches for Industry 4.0: A human resource management perspective", IEEE Congress on Evolutionary Computation (CEC), Vancouver, BC, Canada, 2016, pp. 5309-5316.

[37] Duarte, S., and V. Cruz Machado, “Green and Lean Implementation: An Assessment in the Automotive Industry”, International Journal of Lean Six Sigma 8 (1), pp. 65–88.

[38] Schumacher, A., T. Nemeth, and W. Sihn, “Road mapping towards Industrial Digitalization Based on an Industry 4.0 Maturity Model for Manufacturing Enterprises”, 12th CIRP Conference on Intelligent Computation in Manufacturing Engineering, 18–20 July 2018, Gulf of Naples, Italy, vol. 79, 2019, pp. 409–414.

[39] Duarte, S., “Lean-Green 4.0: A Starting Point for an Assessment Model”, In: McDermott, O., Rosa, A., Sá, J.C., Toner, A. (eds) Lean, Green and Sustainability”, ELEC 2022, IFIP Advances in Information and Communication Technology, vol. 668, 2022, Springer, Cham.

[40] Ghaithan, Ahmed, Mohammed Khan, Awsan Mohammed, and Laith Hadidi, "Impact of Industry 4.0 and Lean Manufacturing on the Sustainability Performance of Plastic and Petrochemical Organizations in Saudi Arabia", Sustainability vol. 13 no. 20: 11252.

[41] Müller, Julian Marius, Daniel Kiel, and Kai-Ingo Voigt, "What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability", Sustainability, vol. 10 no. 1: pp. 247.

[42] Ibarra, D., J. Ganzarain, and J. I. Igartua, “Business Model Innovation through Industry 4.0: A Review”, 11th International Conference Interdisciplinarity in Engineering, INTER-ENG 2017, Tirgu Mures, Romania, vol. 22, 5–6 October 2017, pp. 4–10.

[43] Indonesia Ministry of Industry. Indonesia Industry 4.0 Readiness Index. 2018.

[44] Mahender Singh Kaswan, Rajeev Rathi, Jennifer Cross, Jose Arturo Garza-Reyes, Jiju Antony, Vishwas Yadav, “Integrating Green Lean Six Sigma and industry 4.0: a conceptual framework”, Journal of Manufacturing Technology Management, vol. 34 (1), 2023, pp. 87–121.

[45] Ramos, A. R., J. C. E. Ferreira, V. Kumar, J. A. Garza-Reyes, and A. Cherrafi, “A Lean and Cleaner Production Benchmarking Method for Sustainability Assessment: A Study of Manufacturing Companies in Brazil”, Journal of Cleaner Production 177, 2018, pp. 218–231.

[46] Verrier, B., B. Rose, and E. Caillaud, “Lean and Green Strategy: The Lean and Green House and Maturity Deployment Model”, Journal of Cleaner Production 116, 2016, pp. 150–156.

[47] Brito, M.F., Ramos, A.L., Carneiro, P. and Gonçalves, M.A., "A continuous improvement assessment tool, considering lean, safety and ergonomics", International Journal of Lean Six Sigma, vol. 11 no. 5, 2018, pp. 879-902.

[48] N.H. Hayri, “Industry 4.0 impact on franchising network governance”, 14th International Conference on Knowledge, Economy and Management Proceedings, Istanbul, 2018, pp. 191-196.

[49] H. Dora, and S.R. Zs., “Driving forces and barriers of Industry 4.0: do multinational and small and medium-sized companies have equal opportunities?”, Technological Forecasting and Social Change, Vol. 146, 2019, pp. 119-132.

[50] B. Methavitakul and S. Santiteerakul, "Analysis of key dimension and sub-dimension for Supply Chian of Industry to fourth Industry Performance Measurement", IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), Singapore, 2018, pp. 191-195.

[51] P.B. Anthon, “Rapidly Arriving Futures: Future Readiness for Industry 4.0”. The South African Journal of Industrial Engineering, vol. 29 (3), 2018, pp. 148-160.

[52] S. Jan, K. Matthias, K. Felix, L. Armin, V. Alexander, “Making existing production systems Industry 4.0-ready”, Prod. Eng. Res. Devel. **9**, 2015, 143–148.

[53] L, Bassi, "Industry 4.0: Hope, hype or revolution?", IEEE 3rd International Forum on Research and Technologies for Society and Industry (RTSI), Modena, Italy, 2017, pp. 1-6.

[54] S. Zanero, “Cyber-physical systems”, Computer 50 (4), 2017, pp. 14-16.

[55] A, Thabit., G.S. Zsigmond, and P. Szilard, “Cloud computing and big data in the context of industry 4.0: opportunities and challenges”, (No. 7508667), Proceedings of the Proceedings of the IISES Annual Conference, International Institute of Social and Economic Sciences, Sevilla, 2018, pp. 9-15.

[56] S. Francesco, “Digital Twin Technology in the Industry 4.0 Context”, Doctoral dissertation, Politecnico di Torino, Turin, 2019.

[57] P. Samaranayake, K. Ramanathan and T. Laosirihongthong, "Implementing industry 4.0 — A technological readiness perspective," IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Singapore, 2017, pp. 529-533.

[58] S. Rodrigues, Vasco, and M. Kumar, “Synergies and Misalignments in Lean and Green Practices: A Logistics Industry Perspective”, Production Planning & Control, vol. 30 (5–6), 2019, pp. 369–384.