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# Development of Lean 4.0 Readiness Assessment Tool

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## ABSTRACT

*The concept of sustainable development focuses on efficient resource utilization and waste minimization, aligning with lean principles, forming the basis for implementing Industry 4.0. When Industry 4.0 technology is applied to inefficient processes, it can exacerbate waste. The integration of these principles, known as Lean 4.0, addresses future challenges by enhancing efficiency, flexibility, and production quality. The initial step toward Industry 4.0 involves evaluating the maturity of lean implementation and readiness for Industry 4.0. However, there is a lack of a unified assessment tool for Lean 4.0, prompting this study to adapt existing tools. Utilizing INDI 4.0 as a reference model for Industry 4.0 readiness in Indonesian companies, the research proposes modifications to create the Lean 4.0 Readiness Assessment Tool, incorporating indicators for both lean and Industry 4.0 readiness. The study employs the Delphi Method for indicator validation. Delphi 1 aims to achieve consensus on suitable indicators to serve as guidelines in the assessment tool, while Delphi 2 seeks expert opinions regarding the importance levels of each indicator. This study suggests 5 dimensions and 69 indicators.*

**KEYWORDS:** Industry 4.0, Lean, Lean 4.0, Readiness Assessment Tool, Sustainable Development

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## 1. INTRODUCTION

Implementing Industry 4.0 in a company cannot be done abruptly but requires readiness across all elements within a company's ecosystem. This includes preparing employees with new skills, developing advanced technological infrastructure, and transforming business processes for greater efficiency (Muhardono et al., 2022; Perwira & Hernita, 2021). Success in adopting Industry 4.0 involves not only technological changes but also cultural and mindset shifts underlying the entire organization. Therefore, an assessment tool is needed to measure a company's readiness level for implementing Industry 4.0. Industry 4.0 signifies a significant change in the manufacturing sector, emphasizing collaboration with the latest technology to achieve maximum output with minimal resources (Kamble et al., 2018). The potential of Industry 4.0 can contribute to sustainable industries in social, economic, and environmental dimensions by improving resource efficiency (Sharma et al., 2020). The concept of sustainable development focuses on efficient resource utilization and waste minimization, aligning with the lean concept.

Lean, rooted in continuous improvement, aims to minimize waste and enhance value-added for maximum customer benefit (Gaspersz & Fontana, 2011). Lean serves as the foundation for implementing Industry 4.0 (Dombrowski & Richter, 2018). Without applying lean principles, the deployment of Industry 4.0 technology may lead to increased waste rather than its reduction. Lean and Industry 4.0 together, known as Lean 4.0, offer a robust framework to address future challenges by improving efficiency, flexibility, and production quality (Gil-Vilda et al., 2021). Lean 4.0 integrates digital technologies to enhance waste detection and reduction in both digital and physical processes (Rossi et al., 2022). This concept aims to reduce waste and complexity. Lean's philosophy, based on synchronization and standardization, has reached its limits amid increasing process complexity (Hoellthaler et al., 2018). Digitalization provides opportunities to overcome lean manufacturing limitations by improving complexity handling and increasing flexibility. The joint implementation of lean and digitalization can enhance productivity, presenting potential business growth opportunities (Prinz et al., 2018).

According to (Mayr et al., 2018) Industry 4.0 can advance lean management by using advanced technology to stabilize and refine efficient production processes. Industry 4.0 addresses lean management limitations by providing real-time data and transparent information, enabling better decision-making. The improved flexibility obtained through Industry 4.0 helps better cope with production environment complexity (Hoellthaler et al., 2018). The transition from lean to Industry 4.0 involves evaluating the maturity of lean implementation and readiness for Industry 4.0, and currently, there is a lack of a unified assessment tool for Lean 4.0. Existing assessments are separate, like the Lean Assessment Tool for lean evaluation and the Industry 4.0 Readiness Assessment Tool for evaluating Industry 4.0 readiness.

Several studies have developed tools to measure the level of Lean implementation in companies, such as the Lean Assessment Tool (LAT) proposed by (Brito et al., 2020) and specific tools for industries like (Muhammad & Karningsih, 2020) LAT for the healthcare sector. Similarly, Industry 4.0 Readiness Assessment Tools, like WMG – An Industry 4.0 Readiness Assessment Tool and others, exist. This research aims to adapt existing tools to create an integrated Lean 4.0 assessment tool that can measure both lean and Industry 4.0 readiness. Using INDI 4.0 as a reference model, this study proposes modifications to create the Lean 4.0 Readiness Assessment Tool. The research employs the Delphi Method for indicator validation.

## 2. LITERATURE REVIEW

### Industry 4.0

The core concept of Industry 4.0 involves the digitization of industrial processes, emphasizing Cyber-Physical Systems (CPS) and the Internet of Things (IoT). This integration creates a smart Cyber-Physical System, combining the virtual and physical worlds in manufacturing operations. Germany envisions a 50% increase in manufacturing productivity while reducing resource consumption through Industry 4.0 implementation (GTAI, 2023). The success of this concept has led other countries worldwide to adopt and apply Industry 4.0 principles in their industrial processes.

### Lean Concept

The Toyota Production System (TPS), introduced by Taiichi Ohno in 1940, is widely known as "Lean," emphasizing systematic waste reduction and non-value-added activities for improved productivity and process efficiency. Lean management, based on continuous improvement, targets the recognition and reduction of non-value-added activities in production or service operations and supply chain management. Five fundamental principles guide Lean management, including specifying customer value, identifying value streams, optimizing workflow, implementing pull-based production, and pursuing perfection through continuous improvement (Womack & Jones, 2003) The concept focuses on three types of activities: Value Added (VA), Non-Value Added but Necessary (NNVA), and Non-Value Added (NVA). In manufacturing, waste, defined as activities without value addition, can lead to inefficiencies and time delays, with nine identified types of waste according to (Gaspersz, 2006). The nine types of waste are Environmental, Health, and Safety (EHS), defects, over production, waiting, non – utilizing employee, transportation, inventory, motion, and excess processing.

### Industry 4.0 Readiness Assessment Tool

The Industry 4.0 Readiness Assessment Tool evaluates an organization's preparedness to embrace Industry 4.0 technologies and concepts. This tool assesses the extent to which a company's technological infrastructure, skills, and culture support the transformation to Industry 4.0, enabling strategic planning for improved readiness. The assessment results aid companies in designing roadmaps or action plans to transition more effectively into the Industry 4.0 era, ensuring they can capitalize on the opportunities presented by this transformative industrial landscape. Here are several prelimenary studies about Industry 4.0 Readiness Assessment Tool.

**TABLE 1.** Preliminary Industry 4.0 Readiness Index Assessment Tools

| No | Assessment | Developer | Year | Structure | Score |
|---|---|---|---|---|---|
| 1 | Indonesia Industry 4.0 Readiness Index (INDI 4.0) | Kemenperin RI | 2018 | 5 dimensions, 17 indicators | 0 – 4 |
| 2 | Singapore Smart Industry Readiness Index (SIRI 4.0) | EDB of Singapore | 2017 | 8 dimensions, 17 indicators | 0 – 5 |
| 3 | Industry 4.0/Digital Operations Self Assessment | Pricewaterhouse Coopers | 2016 | 7 dimensions | 0 – 3 |
| 4 | IMPULS - Industri 4.0 Readiness | VDMA | 2015 | 6 dimensions, 18 indicators | 0 - 5 |
| 5 | WMG - An Industry 4 Readiness Assessment Tool | University of Warwick | 2015 | dimensions, | 1 - 4 |

## Lean Assessment Tool (LAT)

Lean assessment is vital for overseeing the implementation of lean principles within a company, a complex and time-consuming process. It allows companies to evaluate the extent of lean principal implementation easily. During lean improvement efforts, assessing lean levels helps companies understand progress better (Susilawati et al., 2015). The Lean Assessment Tool (LAT) measures lean principal effectiveness using company-specific indicators. LAT's customization ensures focused improvement in lean levels, with adjustments needed for various industries, whether in manufacturing or services. Here are several prelimenary studies about Lean Assessment Tool (LAT).

**TABLE 2.** Preliminary Lean Assessment Tools (LAT)

| No | Article | Year | Number of Dimension | Number of Indicator | Sector |
|---|---|---|---|---|---|
| 1 | Brito et al | 2019 | 9 | 73 | Manufacture |
| 2 | Dodgalih | 2020 | 11 | 46 | Service |
| 3 | Harjanto | 2021 | 13 | 51 | MSMEs |

## Delphi Method

The Delphi Method is a technique for gathering information, making decisions, and determining indicators and parameters through iterative questionnaires filled out by experts in the relevant field. The objective is to achieve consensus by considering the responses of a group of experts across multiple rounds. Delphi characteristics include anonymity, iterative rounds to prevent bias and encourage unbiased opinions, and the use of statistical answers to measure differences in opinions among respondents (Zatar et al., 2016). Delphi implementation involves forming a supervisory team, selecting respondents, informing them about the survey's purpose, distributing questionnaires, organizing responses, and presenting analyzed results for further evaluation in subsequent rounds. The research will utilize two iterations, aiming to achieve consensus on dimensions and indicators and gather expert opinions on the importance of each indicator.

### Triangular Fuzzy Number

Lotfi A. Zadeh introduced fuzzy set theory in 1965 as an alternative to probability theory for addressing uncertain problems. Triangular Fuzzy Number, a subset of fuzzy sets, facilitates measurements related to subjective assessments. It is valuable for depicting complex models and data full of uncertainty through various linguistic labels. Each linguistic label represents a predetermined fuzzy number describing a specific situation. According to (Zhang et al., 2014), Triangular Fuzzy Number can be used for risk assessment, corporate performance analysis, forecasting, and even spatial availability depiction. In the definition process, various linguistic labels are used, each represented by different fuzzy numbers. In this study, a five-point scale is used. After obtaining fuzzy scale values from expert responses, a defuzzification process is needed to convert them into crisp (non-fuzzy) values. Various defuzzification techniques, such as centroid, center average, and maximum defuzzifiers, can be used to obtain non-fuzzy output values for the output variable (Wang, 1997).

**TABLE 3.** Five Point Linguistic Scale

| Scale | Linguistic Label | Fuzzy Number |
|---|---|---|
| 1 | Very Unimportant | (0,0, 0.25) |
| 2 | Not Important | (0, 0.25, 0.5) |
| 3 | Neutral | (0.25, 0.5, 0.75) |
| 4 | Important | (0.5, 0.75, 1) |
| 5 | Very Important | (0.75, 1, 1) |

Source: (Dabin et al., 2021)

## 3. METHODS

A brief overview of methodology is shown in Figure 1. The first step is doing literature review and bibliometric analysis to identify the need for developing a new model. This step presents an overview of existing research and gathers information on relationships and their strengths among studies in the Lean 4.0 Readiness Assessment Tool topic.

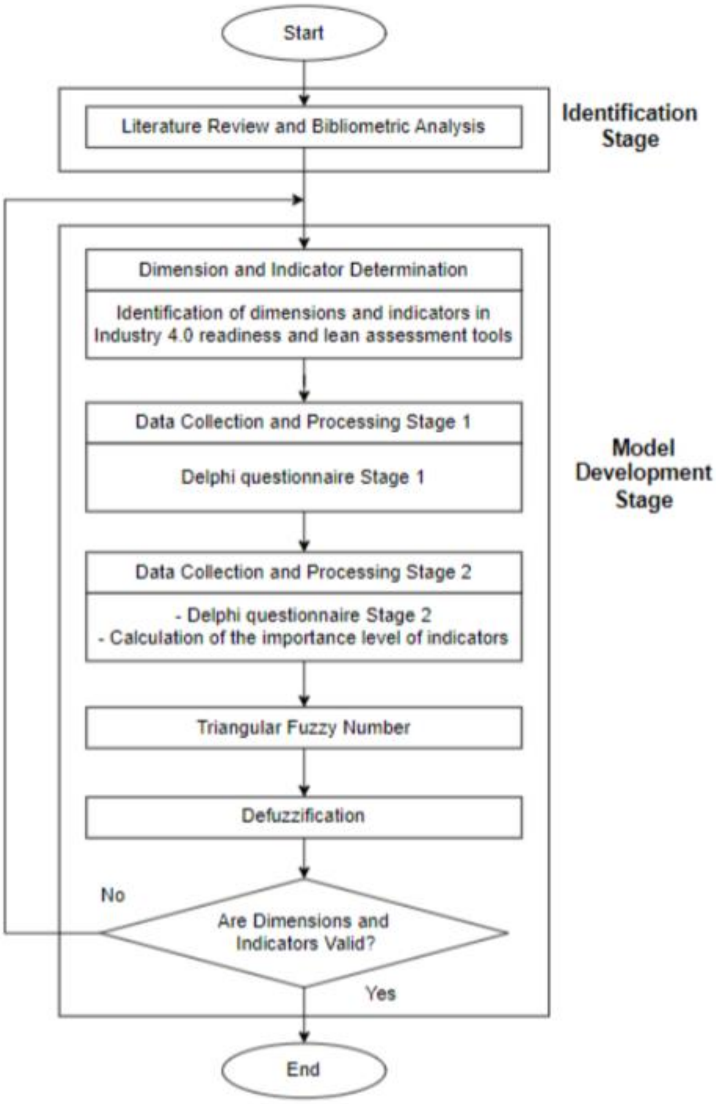


**FIGURE 1.** Methodology Flowchart

### Dimension and Indicator Determination

The basic conceptual model used as a reference in assessing Industry 4.0 readiness is the INDI 4.0 (Indonesia Industry 4.0 Readiness Index) assessment model. The assessment's development involves adjusting questionnaire based on several Lean Assessment Tool models by Brito et al., Harjanto, and Dodgalih.

### Data Collection and Processing Stage 1

The main objective of the first stage of the Delphi Method is to achieve consensus on dimensions and indicators suitable as a guide in the assessment tool. Data collection involves distributing questionnaires to experts in Lean 4.0 implementation, an integration of Lean and Industry 4.0. Experts provide suggestions to modify selected dimensions and indicators based on literature studies. Data processing entails summarizing input from the experts. Three respondents participated as experts in questionnaire completion for this research.

### Data Collection and Processing Stage 2

The primary objective of the second stage of the Delphi Method is to gather opinions from experts regarding the importance level of each indicator. The questionnaire distributed contains the same set of questions as in the first data collection stage but employs a different assessment method. This approach aims to generate readiness scores for Lean 4.0 that reflect real-world conditions.

### Triangular Fuzzy Number

The collected data is further processed using a triangular fuzzy number. In this stage, the Likert scale values obtained from the questionnaire responses are converted into linguistic fuzzy number forms.

### Defuzzification

The next step is to perform defuzzification to obtain more accurate values by converting fuzzy scale values into crisp (non-fuzzy) values for each indicator. In the case of the generated crisp values, if they exceed or at least reach 70%, the indicator is considered valid and can be used in the assessment, as explained by Pandor et al. (2019).

## 4. RESULTS

The determination of dimensions and indicators in this study is based on the reference model, INDI 4.0, which has been modified by incorporating several indicators from previous research related to the Lean Assessment Tool (LAT) with the potential for integration. The dimensions employed in this research align with those in INDI 4.0, encompassing management and organization, people and culture, products and services, technology, and factory operations. The literature review yielded 5 dimensions and 116 indicators, serving as input for the Delphi Questionnaire Stage 1. Respondents, consisting of three expert participants, were selected for their substantial knowledge and experience in both lean and Industry 4.0 within medium to large-scale manufacturing.

For the Delphi Questionnaire Stage 2, the input was derived from the results of Stage 1, comprising 5 dimensions and 124 indicators. Experts, utilizing a Likert scale ranging from 1 to 5 (indicating very unimportant to very important), provided assessments based on the perceived importance of each indicator. Following this, the Triangular Fuzzy Number method was applied to convert Likert scale values obtained from the questionnaire into fuzzy numbers. Subsequently, the defuzzification method was utilized to decide the validity of each indicator. The outcome revealed that 5 dimensions and 69 indicators are considered valid for use in the assessment of Lean 4.0 readiness. Valid dimensions and indicators are shown in Table 4. In Table 4, code A refers to the management and organization dimension, code B to the people and culture dimension, code C to the product and service dimension, code D to the technology dimension, and code E to the factory operations dimension.

**TABLE 1.** Valid Dimensions and Indicators

| Code | Indicator |
|---|---|
| A1 | Management support for Industry 4.0 transformation |
| A2 | Commitment to active management involvement |
| A3 | Leadership attitude in Lean implementation |
| A4 | Leadership attitude in Industry 4.0 technology adoption |
| A5 | Lean approach strategy |
| A6 | Industry 4.0 technology adoption strategy |
| A7 | Management direction related to continuous improvement |
| A8 | Long-term technology investment plan |
| A9 | Allocation of human resources for technology investment |
| A10 | Allocation of costs for technology investment |
| A11 | Reduction of Non-Value-Added Activity |
| A12 | Total cost reduction |
| A13 | Existence of formal policies promoting Industry 4.0 technology innovation |
| A14 | Presence of a dedicated team for Industry 4.0 transformation |
| A15 | Implementation of improvement plans |
| B1 | Implementation of Lean |
| B2 | Efficiency impact in Lean implementation |
| B3 | Reduction of waiting time and cycle time |
| B4 | Workflow balance |
| B5 | Integration of Lean with the principles of Industry 4.0 |
| B6 | Communication about changes in the implementation of Industry 4.0 technology |
| B7 | Employees accustomed to continuous improvement |
| B8 | Analysis of competency development needs related to Lean |
| B9 | Analysis of competency development needs related to Industry 4.0 |
| B10 | Existence of Lean-related training |
| B11 | Existence of training/workshops/certifications for Industry 4.0 technology |
| C1 | Availability of product information systems from vendors |
| C2 | Availability of product information systems to customers |
| C3 | Existence of data analysis from vendors and business partners |
| C4 | Existence of data analysis from customers |
| C5 | Customer feedback mechanisms |
| C6 | Level of customer satisfaction |
| C7 | Data analysis for improving customer service |
| C8 | Data analysis for improving product quality for customers |
| C9 | Level of implementation of big data technology and data analysis |
| C10 | Existence of product integration with technology |

| Code | Indicator |
|---|---|
| C11 | Existence of added value to customers |
| D1 | Cybersecurity implementation |
| D2 | Cybersecurity training |
| D3 | Machine-to-Machine (M2M) connectivity via internet/intranet |
| D4 | Connectivity of systems within the company across different technical disciplines |
| D5 | Implementation of the Internet of Things (IoT) |
| D6 | Implementation of Enterprise Resource Planning (ERP) |
| D7 | Implementation of Radio-Frequency Identification (RFID) |
| D8 | Implementation of Supervisory Control and Data Acquisition (SCADA) |
| D9 | Implementation of Programmable Logic Controller (PLC) |
| D10 | Conversion of manual processes to digital |
| D11 | Level of digitalization within the company |
| D12 | Impact of digitalization on customer interactions |
| E1 | Digital storage of operational data |
| E2 | Using cloud in data storage |
| E3 | Implementation of First In First Out (FIFO) |
| E4 | Just in Time (JIT) principle |
| E5 | Delivery time |
| E6 | Inventory turnover ratio |
| E7 | Standardization of supply chain flow |
| E8 | Logistic integration between company and vendor/supplier |
| E9 | Level of company process automation |
| E10 | Existence of performance indicators for automated process impact on factory operations |
| E11 | Defect rate per month |
| E12 | Inspection by defect control officers |
| E13 | Timely defect product repairs |
| E14 | Reoccurrence of the same issues |
| E15 | Implementation of Plan-Do-Check-Act (PDCA) |
| E16 | Achievement of target and indicator goals |
| E17 | Real-time machine condition monitoring and Overall Equipment Effectiveness (OEE) monitoring system |
| E18 | Predictive maintenance |
| E19 | Preventive maintenance |
| E20 | Corrective maintenance |

## 5. CONCLUSIONS

The Lean 4.0 Readiness Assessment Tool is designed to measure the level of lean implementation (leanness level) and Industry 4.0 readiness (readiness level). This assessment form integrates Lean Assessment Tool and Industry 4.0 Readiness Assessment Tool. The assessment model utilizes the INDI 4.0 reference, consisting of five dimensions: management and organization, people and culture, products and services, technology, and factory operations. The dimensions and indicators obtained from the literature review were then selected and validated by experts using the Delphi method, triangular fuzzy number, and defuzzification. The validation results identified 5 dimensions and 69 indicators. This study can help companies map their organization and partners based on the measured Lean 4.0 readiness level and facilitate companies in building programs towards Lean 4.0.

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