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A maturity model for assessing Digital Green Lean leadership and culture implementation in manufacturing companies

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Lean Manufacturing is continuously transforming in the era of Industry 4.0, merging digital technologies with conventional manufacturing processes focusing on sustainability through Circular Economy principles. This evolution of Business Systems has led to the newly formulated term ‘Digital Green Lean’, which contains the synergy between Lean Manufacturing, Digital transformation, and Sustainability principles.

The research is driven by the need for a maturity assessment for leadership and business culture, enabling companies using Lean Manufacturing principles to evaluate their readiness and alignment with the principles of Industry 4.0 and Circular Economy. Organizations must adapt their Lean practices to remain efficient, digital, sustainable, and competitive.

Method/Findings – The article consists of a literature review on maturity assessment, with the keywords Industry 4.0, Circular Economy, Lean Culture, Lean Leadership, and theoretical development for the maturity assessment, including evaluation criteria.

The assessment includes (1) three dimensions, ten subdimensions, and 38 systems for Digital Green Lean Business Culture and (2) four dimensions, 19 subdimensions, and 43 skills for Digital Green Lean Leadership, to be evaluated in a developed five maturity levels.

Implications – This research includes the first development of a maturity prescriptive and comparative assessment for companies to assess, compare, and develop action plans in their Lean journey within the context of Industry 4.0, Circular Economy, Lean Culture, and Lean Leadership, as part of the new integrated Digital Green Lean (DGL).

Keywords: Maturity assessment; Lean Manufacturing; organizational culture; leadership; Industry 4.0; Digital Transformation; Circular Economy; Sustainability

1. Introduction

The Toyota Production System (TPS) has been widely studied since the 1980s following the publication of the book ‘Toyota Production System’ (Toyota Motor Co, 1973) by Toyota, and it has regained interest in recent years. These studies cover the tools, but recently, the literature shows that implementing Lean Leadership and Culture systems is critical in achieving and maintaining performance improvements for companies operating in Lean Manufacturing environments (Dorval et al., 2019; Liker, 2004; Spear, 2004).

The Fourth Industrial Revolution has emerged based on the industry’s application and integration of new digital technologies. This concept of Industry 4.0, or the fourth industrial revolution, arose in Germany in 2011 through a government initiative published by

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Kagermann et al. (2013) and represents a profound change in the organizational structure of companies. It is expected that the result of the Fourth Industrial Revolution will be the Smart Factory, or Smart Productivity, where Cyber-Physical Systems (CPS), the Internet of Things (IoT), Blockchain, and Big Data are the key technologies to achieve productivity goals.

Modern society is reducing the volume of material usage of economic systems to the carrying capacity of the planet's ecosystems through concepts like reusing, recycling, and remanufacturing. This means a radical decrease in economic systems' material and energy intensity (Melnik et al., 2019), and this is where the Circular Economy kicks in. The concept evolved from a Smart Factory to a Smart Green Factory.

All the previous concepts are merged under one newly developed concept and lead to the definition of 'Digital Green Lean' (DGL) (Gatell & Avella, 2024). It forms the foundation for exploring the current manufacturing landscape and gives companies a tool to evaluate their maturity in its implementation.

DGL helps us understand the impact of different aspects of current manufacturing on each other. By including sustainability, technological developments through Industry 4.0, Lean efficient practices, Lean culture, and Lean leadership, DGL is the basis for companies to evaluate and enhance their operational strategies. It enables organizations to adjust to the changing manufacturing environment while emphasizing environmental responsibility and resource efficiency.

With the concept of DGL in mind, we check the existence of a maturity model to assess the implementation grade and propose a new or improved maturity model that could add value to the organizations. A maturity model represents a desired, anticipated, or typical evolution path of a sequence of maturity levels for objects shaped as discrete stages (Becker et al., 2009). Becker et al. (2009) also includes a classification for maturity models as descriptive, prescriptive, or comparative. If the model is explanatory, the entry will be a single point, and the result will be without provision to improve maturity or assess the current condition. If prescriptive, it focuses on business performance over time and shows how to improve maturity, positively affecting the business. Moreover, if comparative, it will also provide benchmarking across industries or regions.

We can, at this point, include the research question that will be studied in this paper:

RQ: How can the design and development of a maturity model provide insights, recommendations, and foresight to organizations implementing Digital Green Lean to enhance the efficient management of its implementation, especially regarding organizational culture and leadership?

It is essential to investigate through a Systematic Literature Review (SLR) whether any maturity model in the literature or practice assesses the level of Industry 4.0 and Circular Economy implementation within the context of Lean Manufacturing. It should evaluate the traditional Lean practices and include topics related to Industry 4.0 and Circular Economy in the Leadership and Business Culture aspects. Besides, it should offer companies meaningful insights, recommendations, and foresight. If this model does not exist, a new model can be developed to effectively manage the implementation of DGL Leadership and Culture aspects.

2. Background

De Bruin et al. (2005) define the design of a maturity assessment framework in phases: scope, design, populate, test, deploy, and maintain. Also, Skalli et al. (2023) include

four core properties: (1) stages or levels, (2) dimensions, (3) sub-dimensions, and (4) capabilities/systems creating a suitable framework (evolution versus properties) to identify and create, if not available, a maturity assessment model.

The definition of the core properties of a maturity assessment to be used in this research will be as follows:

1. **Stages or levels of maturity:** Sequential stages of growth that an organization or a process goes through, reflecting its degree of advancement, proficiency, and efficiency.
2. **Dimensions:** Fundamental aspects or perspectives that contribute to the overall assessment of maturity.
3. **Subdimensions:** Detailed elements or subcategories within each dimension. They represent the breakdown of broader dimensions into more specific components that can be assessed individually.
4. **Capabilities and systems:** Specific abilities, competencies, functionalities, or frameworks that contribute to the overall maturity of an organization or process (both tangible and intangible). Assessing capabilities or systems involves determining the presence, strength, and integration of critical elements driving maturity within each dimension and subdimension.

A Summary of these four properties and their interaction can be displayed in [Figure 1](#).

All the information and the existing bibliography on maturity models will help the authors in this paper define a proper methodology to respond to the research question. A Systematic Literature Review (SLR) should limit bias in the assembly, critical appraisal, and synthesis of all relevant studies that address a specific research question (Seuring et al., 2020). Thus, this research paper starts with an SLR to understand the literature on maturity assessments in Lean Leadership, Lean Culture, Industry 4.0, Circular Economy, and their Boolean combinations (and/or).

To start working on the SLR, the paper selection criteria and analysis methodology are described below:

1. **Gross Search:** Search keywords in Web of Science and Scopus databases.
2. **NET / Refined Search:** Filter articles by language (English or Spanish, the mother language of the authors). There is no publication time restriction.

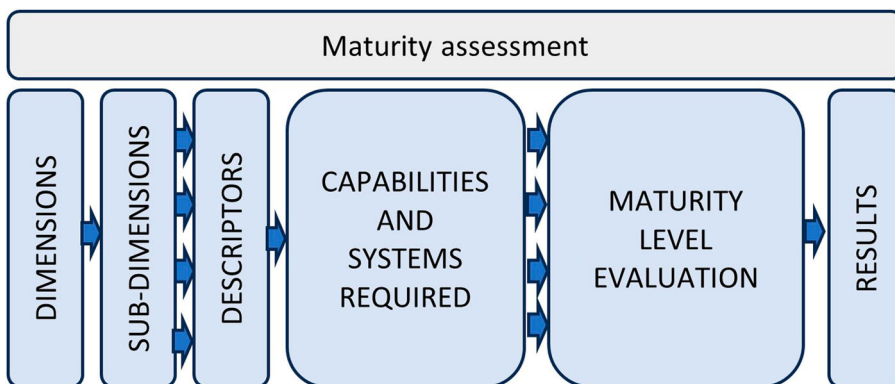


Figure 1. Visual representation of a maturity assessment.

3. **Preliminary Analysis:** Remove duplications on title/DOI.
4. **Relevant:** Analyze titles and abstracts to remove articles unrelated to the topic. Include relevant articles obtained from the narrative review.
5. **Final Relevant:** Read all remaining articles in-depth, capturing this paper's required information and removing articles that do not contain relevant information.

A search question has been run in Web of Science and Scopus databases to find any paper related to Lean Manufacturing Culture and Leadership, with Industry 4.0 and Circular, that will provide information on the availability of a maturity assessment and how to perform it.

2.1. SLR for the maturity assessment lean & culture, leadership, industry4.0, and circular economy

The outcome of this SLR should be a comprehensive assessment that includes the three concepts of Lean Manufacturing, culture and leadership, Industry 4.0, and Circular Economy blended into one unique maturity evaluation system.

Search Question (Table 1): **(Maturity OR Assessment) AND (lean AND (culture OR leadership) AND (industry 4.0 OR circular-economy OR digital OR green))**

In this search, despite the final relevant articles, including the terms in the search, the maturity assessments need to be more comprehensive and cover the aspects of culture and leadership plus Industry 4.0 and Circular Economy, which we seek.

From an initial search of 46 documents, one was eliminated due to language, 23 were eliminated due to repetitions in the title or DOI, 12 were eliminated after reading the abstract and most relevant information, and five were eliminated after reading the entire paper. One was added to the narrative review. The total number of final relevant documents is five.

In the final five relevant articles, we can find, in whole or partially, the use of the same maturity assessment concepts described before (Skalli et al., 2023).

2.1.1. Stages or levels of maturity

Out of the five final documents, only two define different stages of maturity, modified by the industry and sector they are researching, and focus either on Industry 4.0, Circular Economy, or Sustainability/Green. Tortorella and Fogliatto (2017) also define the Lean Implementation phases. However, none propose stages for combining Lean Leadership and Culture, Industry 4.0, and Circular Economy.

The maturity levels proposed in the two papers found in this part of the SLR are depicted in Table 2. All of them range from a firefighting, reactive, or even infancy

Table 1. Relevant articles for SLR.

	Web of Science	Scopus
1 Gross search	28	18
2 Net (language filter)	27	18
3 Preliminary (merging and duplication elimination)	22	
4 Relevant (first analysis of abstracts and inclusion of narrative review relevant papers)	9 + 1NR	
5 Final relevant (Detailed reading of papers)	5	

Table 2: Maturity levels.

(Skalli et al., 2023)	(Treviño-Elizondo et al., 2023)
– Infancy: The company has planning for the implementation of Industry 4.0	– Value (process): Clear Vision of the value stream. – Sensitization (people): Current gaps in I4.0 to develop workers' skills. – Usable (Product): Customer wants and expects.
– Advanced: The company has developed vision 4.0 and workforce 4.0	– Integration (process): connecting processes and standardizing cross-departmental information. – Adequacy (people): a training program to develop skills. – Traceable (product): Definitions of Customer use of the product.
– Skilled: The company started to deploy strategy 4.0 and pilot project	– Intelligence (process): automated decision-making processes and Business intelligence. – Adoption (people): Advanced technologies to support workers in data and decision-making. – Analyzable (product): The product provides data on usage.
– Proficient: The company has succeeded in its pilot project	– Collaboration (process): Between digitally interconnected processes and departments. – Promotion (people): High-performance teams. – Connected (product): The product connects, interacts, and shares information. – Autonomy (process): Flexible, adaptable, and innovative processes. – Culture (people): Best practices sharing and transferring. – Interactive (product): The product takes the initiative to look for interaction with smart devices.

level of systems maturity at the beginning to a culturally embedded system, proficient or autonomous systems at the maximum maturity.

2.1.2. Dimensions/subdimensions

In the same way as the previous point, four of the five papers define different dimensions for a maturity assessment. However, they are only part of the research question we are investigating. Nevertheless, showing them four here is essential as they provide valuable information when defining and proposing a maturity assessment (Table 3).

We are looking for a maturity assessment focused on an organization's Leadership and Cultural aspects. Therefore, this table can be used as a starting point to define the dimensions in Section 3.2.

2.1.3. Capabilities/systems

While defining the capabilities existing in the bibliography, we have found two articles that connect with our research, one with the title of 'Lean-Green 4.0: A starting point for an assessment model' (Duarte, 2023), whose author gives an interesting approach to the

Table 3. Dimensions in literature.

(Skalli et al., 2023)	(Treviño-Elizondo et al., 2023)	(Duarte, 2023)	(Gatell & Avella, 2024)
Technology	Smart Processes	Leadership and Strategy	Lean Culture: Values and Principles
Smart Value Chain	Smart People	People	Lean Culture: Customer Centric
Culture and People	Smart Products	Product	Lean Culture: Operational Excellence
External Environment		Process	Lean Leadership: Customer-Oriented
		Customer	Lean Leadership: Personal Development
		Supplier	Lean Leadership: Lean Principles
		Technology	Lean Leadership: Performance Driven
		Governance	

capabilities or systems (‘Measurement items’ in his research), and another one that defines the competencies required for leaders managing Digital Transformation (Philip et al., 2023). Both could be a starting point for developing the capabilities section from a maturity assessment (Table 7).

Duarte (2023) proposes a baseline framework to design an assessment model for implementing Lean and green management in an Industry 4.0 environment. Different dimensions were identified: ‘leadership and strategy, people, process, product, customer, supplier, governance, and technology’. Moreover, measurement items under each dimension show the author’s proposal on skills/capabilities for implementing such dimensions. The proposed framework is a starting point for designing an assessment model to guide the deployment of Lean and green management characteristics within the new industrial era. However, it does not include a direct connection with the Company’s Cultural aspects.

The maturity models in the literature cover either Industry 4.0 in the Lean industry, the most common, or the Sustainability or green production in Lean companies. However, none of them are focused on Leadership and Culture as primary drivers for the Toyota Production System or Lean Manufacturing implementation as discussed by scholars (Liker, 2004).

In conclusion, for this SLR, any of the maturity models can evaluate the maturity of Leadership, Culture, Industry 4.0, and Circular Economy in those companies working under the umbrella of Lean Manufacturing. Despite some bits and pieces in the bibliography, to the best of our knowledge, a full maturity assessment has yet to be developed for Digital Green Lean Culture and Leadership as of December 2023, which allows us to certify a research gap to be covered.

3. Methodology: creating a DGL culture and leadership maturity model

This section outlines the methodology for addressing the research question (RQ) and bridging the identified research gap. We include the steps to develop a robust maturity model that assesses the implementation of Industry 4.0 and Circular Economy within companies operating under Lean Manufacturing. The design and development of this model considers

all studies examined during the Systematic Literature Review (SLR) process, ensuring the integration of perspectives and insights from the existing papers. This approach provides the robustness and relevance of the proposed model by incorporating best practices and insights identified during the systematic review.

This section defines dimensions, subdimensions, and descriptors for Lean Manufacturing culture and leadership, Industry 4.0, and Circular Economy. Later, we determine the capabilities or systems required for assessing the maturity. All these pieces will give the maturity assessment model, shown in Section 3.4.

3.1. Stages or levels of DGL leadership and culture maturity

We need to start with the different maturity levels to define the maturity model. Setianto and Haddud (2016) proposed a set of maturity levels when presenting a maturity model for Lean development practices in the manufacturing industry that are used as a starting point for this paper; however, enhanced and redefined for the concepts we are using here with the new papers found through the SLR as outlined in Section 2. Table 4 includes the final levels of maturity considered in this article and defined in depth by the authors for the new maturity assessment.

3.2. Dimensions, Subdimensions and Descriptors

After defining the levels of maturity to be used in our maturity assessment, we proceed to represent the different dimensions and subdimensions to be used and explain them through descriptors. The two searches before in the SLR are used to describe Business Culture and Leadership. The starting point is mainly the work done by Setianto and Haddud (2016), Duarte (2023), and Gatell and Avella (2024). The dimensions and subdimensions

Table 4. Final defined levels of maturity.

Maturity level	Definition
REACTIVE	Reactive and firefighting. No problem-solving in place. No planning or strategy. Isolated employees without autonomy: No planning of I4.0 or CE, their applicable tools, or implementation. Issues are dealt with when they happen with no formal structure.
FORMAL	Formal working structure with team learning. First, standards (policies, procedures, processes) are developed – essential Planning. Only area/topic specialists work with autonomy. There is an I4.0 plan, and the first circularities appear in the organization.
DEPLOYED	Systems and skills are deployed in dedicated teams and are goal-oriented towards Vision and Values. Process standardization. Planning, scheduling, and resourcing in place. Vision has been developed for I4.0 and CE implementation through employees.
AUTONOMOUS	Managed autonomously, most employees are involved at all levels – process learning. Processes interconnected. The organization deploys applicable I40 tools, implements internal and external circularities, and defines pilots where successful implementation can be measured.
WAY OF LIFE (CULTURE)	Continuous improvement. Daily habit with full empowerment of organization members. The I40 and CE are delivering positive results in the areas where they are applied. Smart people, processes, systems, and products are in place and sustainable.

Table 5. Dimensions and Subdimensions.

Lean culture dimension	Characteristic/subdimension
LC1: Values and Principles	C1: Human orientation, culture of respect C2: Collectivism: In-group and institutional level of unionization C3: Power distance C4: Authority distribution & decision-making, Uncertainty avoidance
LC2: Customer-centric	C5: Sustainable customer orientation C6: Performance orientation
LC3: Operational excellence	C7: Receptiveness C8: Working conditions & SHE (Safety, Health & Environment) C9: Problem solving culture (scientific method) C10: Continuous improvement & innovation
Lean leadership dimension	Competence/subdimension
LL1: Customer-oriented	L1: Customer focus L2: Customer & supplier development L3: Teamworking
LL2: Personal development	L4: Personal stability L5: Personal behavior L6: Human-centric L7: Self-developing and learning L8: Empowerment L9: Self-transcendence L10: Servant
LL3: Lean principles	L11: Experimental L12: Continuous improvement and innovation L13: Zero-defects L14: Process and lean expertise L15: Problem-solving L16: Genchi genbutsu
LL4: Performance driven	L17: Target setting L18: Targets deployment L19: Flow

defined are displayed in [Table 5](#). We can present the ‘Characteristics’ as the subdimensions in the Lean Culture and the ‘Competences’ as the subdimensions in the Lean Leadership.

Each of the subdimensions requires a description. The descriptor analyzes and describes the systems and processes needed for an organization to achieve DGL Culture or Leadership. Descriptors will help the organization take the high-level concept of Dimension and Subdimensions and turn them into actionable items, processes, systems, and behaviors expected to be implemented on the shop floor developed by the organizational leaders. Descriptors are generated based on the DGL methodology and the impacts of Industry 4.0 and Circular Economy in Lean Leadership and Culture. It considers DGL a unique working system, not an addition of three different systems.

The descriptors for the defined dimensions and subdimensions of Culture and leadership are identified in [Table 6](#) below.

3.3. *Capabilities/Systems*

Once we have perfectly defined the dimensions and subdimensions through the descriptors, we must define what systems should run in the organization to ensure effective

Table 6. Descriptors for each subdimension

Dim	Sub	Descriptor
LC1	C1	• The company is developing and implementing policies for equal opportunities, fairness, and employee care. It engages the employees to become asset protectors. Systems are in place to support this. • Company is human-centric: Autonomous robots are introduced to support operations. Employees only supervise. Humans are prioritized versus technology for low-physical intensity jobs. The impact of interconnectivity and robotization would be fairness, equal opportunities, and employee care. • The whole organization is focused on sustainability and conserving natural resources.
	C2	• Employees express pride, loyalty, and cohesiveness and collaborate for a better company. Organizational policies and practices encourage and reward teamwork and collective action through teams, committees, or any other form of unionism. • The company promotes the association of employees in different internal and external groups and measures benefits. (e.g. Formal teamworking, health committees, working groups with customers or suppliers, unionism, social responsibility committees ...) Teams are handled, and policies are drafted to control/support them. Employees become ambassadors of the company. National Culture impacts global or local policies, and it is measured. • Employee participates in operational decisions and SHE improvements. Consensus is reached for key operational innovations, including technology and process redesign for circularity. • The decentralized and agile decision-making process's impact is measured and improves teamwork. Technology and robotics are more variable. Circularity does not erode the team's cohesiveness and the leader's leadership style.
	C3	• Organization design, spans of control, easiness of communication, and the degree to which members expect and agree that power should be unequally shared. • The systems to design organization structures and manning requirements, including robots, cobots, and other technology enhancements. Vertical and horizontal communication is embedded in the design of the organization. Employees accept the mandates by conviction and not by bureaucracy. The coaching policy is deployed and measured in the results.
	C4	• Personal authority distribution is done at all levels of the organization; there are control mechanisms to balance human/machine decisions, failure is tolerated, and consequences of failure are known. Employees strive to avoid uncertainty by relying on social norms, rituals, and standard practices to alleviate the unpredictability of future events. • There are controls to prevent biases, and the decisions are fact-based, removing tradition or intuition. • Job insecurity is dealt with to avoid uncertainty of the future due to the introduction of new technologies or circularities.

(Continued)

Table 6. Continued.

Dim	Sub	Descriptor
		• By using big data, analytics, and integration online of the physical systems, the variability of the processes is reduced. There is a strategy for data-handling and decision-making considering technology output. • Recyclability and reuse to reduce material usage impact the process variation. The uncertainty and the decision-making policies contemplate it. A straightforward problem-solving process is in place. A strategy exists to eliminate and minimize or control uncertainty in any system or process. • There is a balance between Lean, I40, and sustainability in product and process development.
LC2	C5	• The organization focuses the systems on sustainability and long-term customer relationships. • Customers engage in future-oriented policies such as planning, investing in the future, systems integration, and big data. • The organization builds long-term relationships with customers, including retention methods. • Organization handles the new type of customer: Moves from owning to leasing and impacts the circularity and productivity.
	C6	• The organization sets vision, mission, and values and converts them into long-term and short-term strategies for all aspects of the business, e.g. manufacturing, technology, and sustainability. It includes a strategy deployment system and measurement to track the implementation of the strategy. • Organization rewards group members for performance improvement. Employees are motivated to meet and exceed their personal and technical targets. There is a learning and development plan to train all employees in new skills coming from the strategy (e.g. new technologies, Industry 4.0, blockchain, data analytics, cyber-physical systems, circularity, sustainability, waste, and recycling strategies) • Circularity includes Customer products and by-products. The impact of the reuse and higher recyclability is measured and reported for continuous improvement. Policies and systems are in place to deal with waste in the long term, targeting zero waste. • Inner and extended circle projects enhance operational performance and productivity and are built-in as part of the process design. Cloud computing: Data is stored in the cloud and interconnectable. • Data is integrated along the value stream for decision-making and process performance. Internet of Things, Analytics, and real-time data improve production performance in a learning organization.
LC3	C7	• The company promotes social relationships with the community and other stakeholders. Digitalization of processes does not jeopardize the intent of clear communication. There is a process to deal with conflict. There are mechanisms to handle difficult situations and conflicts between employees, leaders, or areas. • There is no conflict between machines and humans; priority is given to human employees. Information, data, and analytics from technical systems are used in problem-solving and other innovation systems.
	C8	• There are SHE, working conditions, and ergonomic policies and systems. They are communicated and implemented across the employees; they participate in making their jobs safer and healthier. The best available technologies are used to separate man-machine to minimize risks. There is a system to deal with human error in SHE-related topics.

- There is a strategy to place autonomous robots in high-risk areas and cobots requiring high physical effort. The technology eliminates, minimizes, or controls SHE risks. Results are measured through data analytics of big data.
 - There are systems in place to minimize the impact of the circularity (e.g. increase of recycling, internal and external, longer cycles, more use of scrap, reusing policies ...). The employees are trained.
 - Redesign of operational processes, including inner circles and reviewing working conditions and SHE.
- C9
- The organization strives to eliminate non-value-added activities. Participating employees are trained and coached in problem-solving by leaders. Information technologies are used for data-based analysis and faster decision-making.
 - Production lines and cycles are constantly improved before digitalization to avoid automating the error. Simulations are done for every process or product redesign to optimize the improvement cycle and cost.
- C10
- The Organizational mindset of everything can be improved. It is set in the policies and deployed to all employees. Innovation policies and systems are used by employee participation at all levels. Employees are recognized and rewarded for their collaboration on innovation and continuous improvement.
 - Innovation and continuous improvement culture include applying digital activities, new technologies, cyber-physical and security systems, sustainability policies, and process redesign to include circularities.
 - The operational redesign process includes circularity as a critical building block, extending the use of recycling materials as part of new operational processes (Cascade use)
- LL1 L1
- The company is focused on deliverables for internal and external customers. Customer needs are above individual or group needs. Customer targets are more important than individual targets.
 - External Customer processes are designed and integrated with Company data availability and analytics.
 - Leader competencies include customer focus, digitization, and sustainability to develop new digital circular processes for them.
 - Customer evolves into a data provider and becomes part of the production digital loop.
- L2
- DGL is developed for customers and suppliers. Systems integration is in place to achieve higher levels of efficiency through process communication (IoT) improvement and waste elimination.
 - Leaders are capable, knowledgeable, and have tools to develop DGL in their internal and external Customers and Suppliers. Leaders have clear role descriptions and authority.
- L3
- Leaders have straightforward organization and spans of control that guarantee employee coaching and development (ratio depends on the job complexity)
 - Leaders develop proper communication and transparency and have the social ability to make contacts. Robots are considered part of the team and an essential input for problem-solving and decision-making.

(Continued)

Table 6. Continued.

Dim	Sub	Descriptor
		• Leaders consider teams above individuals and design the organization structure with new technologies (e.g. IoT, AR, Big Data, Robots, system integration, cloud computing, cyber systems, sustainability, circularity, cascade use ...)
LL2	L4	• There is a promotion policy, including horizontal promotions. Each position has minimum skills and stability to gain expertise and coaching. • < UNK > A leader's evaluation system is based on soft skills, personal development, and hard skills. There is a skill-development matrix for leaders.
	L5	• Company culture is embedded in the daily work of the leader, creating role models. • Servant leadership style includes hansei (self-reflection), self-awareness, and assessment. Modesty & humility. Empathy. Credibility. Leaders promote professional relationships with the employees and are accessible. • The implementation of new technologies is done with collaboration and consensus with the team and puts the company's benefits above individual or team objectives. • Company leaders are experts in leading difficult conversations and managing conflict.
	L6	• The organization has a succession plan process attached to an individual development plan. • Leader constantly develops and coaches his successor and the team. • Leader handles the digitalization strategy and sustainability effort with emotional intelligence and ethics.
	L7	• Constant self-development and learning in a structured way, guided by a coach using available technologies (AR, digital twins ...) • There is a specific leadership skills and competencies development plan. It includes social/personal/technical skills, new technologies (augmented reality, robotics, simulations ...), sustainability, and inner/longer circularity principles.
	L8	• The company promotes team empowerment and fact-based decisions after data gathering and analysis. • Delegation of authority and accountability systems in place, measured and effective. Facts are separated from opinions for decision-making. • Data is shared across and not individual property. Autonomous robots, deep learning, and other systems provide data to the organization where/when it is needed or on demand.
	L9	• Leaders set the true north and strive for perfection by visualizing greatness (self-transcendence). Leaders have physical and psychological strength and understand their contribution to the organization's future and influence on employees' personal and social lives. • Leaders are allowed and willing to take challenges with implementing new technologies and are not afraid of consequences. • Their critical role in the organization is reinforced and empowered. (self-esteem, self-transcendence, and motivation).

- L10 • Leaders follow the servant model and are encouraged to be humble, trustful, listen to others, respectful, and fair.
- Leaders use the new technologies development and sustainability principles to teach and develop their teams. (AR, Digital Twins, robots ...)
- LL3 L11 • Leaders use data analysis, experimentation, hypothesis testing, and trial (Kata): Standardizing the results, communicating the improvements, and recognizing the employees.
- New technologies enhance performance and increase productivity by designing experiments, simulations, big data, deep learning, artificial intelligence, or other suitable technologies.
- Leaders balance technology implementation and sustainability to get the best for the organization.
- L12 • Organization promotes disciplined CI and Innovation through critical thinking, intellectual stimulation, and risk management.
- System design includes new technologies (e.g. IoT, Big data and analytics, robots, simulations, cyber systems, and 3D manufacturing) and Circularity as critical elements. Results are more efficiency, less waste, higher productivity, and employees more engaged.
- L13 • There is a zero-defect mindset and tolerance for mistakes and failure when they happen.
- Human error is dealt with based on intentionality and consequences through a progressive consequences policy. Learning is captured when mistakes happen.
- There is a process to handle variability and error produced by the autonomous robots connected (IoT) and the consequences implemented.
- L14 • There is a process and knowledge to design, implement, and improve flow, takt time, and standardize work.
- Leaders use augmented reality, big data, deep learning, artificial intelligence, robots, and other technology to support lean principles and improve process design, including circularities, sustainability, and productivity.
- L15 • Leader masters scientific problem-solving, data analysis, root cause analysis, and simulation as a way of thinking. Teaches and guides others.
- Information technologies are used for data analysis and decision-making. Production lines, robots, and cycles are connected (IoT), integrated, and constantly improved. To optimize the improvement cycle and cost, deep learning and simulations occur for every process/product redesign.
- L16 • Leaders are constantly on the shop floor as a philosophy for data-gathering, understanding the situation, circularity status, and coaching. Visual management and digital data visualization are key facilitators.
- Data gathering implementation is done where the data is needed, avoiding central data controls as much as possible. A daily management system requires augmented reality, simulations, and deep learning (AI).
- LL4 L17 • There is a system to communicate its vision, mission, and values as long-term and short-term targets using digital information and quick data access. Targets for AI and autonomous robots are set separately and are part of the leader's responsibility.
- Leaders recognize and reward achievements in real-time on the shop floor.

(Continued)

Table 6. Continued.

Dim	Sub	Descriptor
L18		• Consistent and transparent target deployment and tracking (Hoshin Kanri). Reward and recognize success. • Autonomous robots, deep learning, AI, circularity, cascade use, and other new processes implemented are included in those targets. Responsibility for the outcome stays with the process owner.
L19		• Leaders understand and use flow, system integration, stability, leveling, balancing, and inner and extended circles concepts. Manage flow rather than isolated operations with available tools like AR, Big data, cloud computing, simulation, deep learning, or digital twins. • Leaders improve processes from linear design to circular flow, where possible, using all the new technologies and tools and ensuring productivity and sustainability are maintained.

implementation of those dimensions and subdimensions for business culture and what skills the leaders must have to implement DGL effectively. This will provide the framework to evaluate the DGL maturity of the organization.

Systems for DGL Culture and Skills for DGL Leadership are developed based on existing tools, systems, and processes but tailored to a holistic system like DGL. The author's operational and academic experience has been used to create them. These tools, systems, and methods are now defined to include all the requirements so companies can benefit from this model, knowing the gaps of their systems versus DGL and being able to prepare a specific implementation plan for the gaps found.

The development of those systems should include everything needed for its management, such as the development of policies, processes, and procedures accordingly. [Table 7](#) captures all the systems and skills in place required.

3.4. *Maturity model proposed*

Based on all the DGL Culture Characteristics defined and DGL Leadership competencies proposed, and considering the impact that I40 and CE could have on those two concepts, a maturity assessment, prescriptive and comparative, is presented. This will answer our RQ: **How can the design and development of a maturity model provide insights, recommendations, and foresight to organizations implementing Digital Green Lean to enhance the efficient management of its implementation, especially regarding organizational culture and leadership?**

The final design includes maturity levels from Section 3.1, dimensions, subdimensions, descriptors from Section 3.2, and capabilities/systems to be implemented for a successful DGL implementation from Section 3.3. The template to be used is included in Annex 1 for DGL Culture and Annex 2 for DGL Leadership and summarized in [Figure 2](#).

The organization should analyze the descriptors, systems, and skills required and reflect on how the company performs against the requirements. If any systems are in place and the organization is randomly using those processes, the cell of 'reactive' should be checked. If some standards are in place, procedures, or processes drafted but not spread across the organization, 'formal' is checked. When standard procedures are consistent in all the organizations, 'deployed' is checked. When systems are working without intervention and are effective, the cell 'autonomous' should be checked, and if the systems or skills are how we do things across the target area or organization, then the cell 'way of life' is checked.

This system allows, but is out of the scope of this paper, to assign a value to each cell checked and develop a scoring system for the DGL implementation in an organization. This also helps the organization to perform the same maturity assessment over time, creating a longitudinal assessment to evaluate the implementation of Digital Lean Green, even becoming a performance metric for the company's top leaders.

4. **Final conclusions, limitations and future research**

Lean Manufacturing has been undergoing continuous transformation since its inception. In modern times, new technologies and sustainability have become even more critical to achieving productivity and efficiency through the people in the organization. However, Lean manufacturing cannot work in isolation. Industry 4.0 and the Circular Economy are now indivisible building blocks of the overall business system, creating the concept of Digital Green Lean.

Table 7: Systems, Skills, and capabilities required.

Dim	Sub	Systems/skills/capabilities required
LC1	C1	• Equal opportunities, fairness, employee care • Asset Management • Autonomous Robots strategy • Sustainability
	C2	• Association of employees (internal and external) • National and local culture development • Employee participation in company management • Team-working and robotization • Lean Manufacturing, Agile, and Six Sigma • Leadership
	C3	• Organizational Design (Humans, Robots, Cobots) • Internal Communication • Decision Making Levels • Training, development, coaching and mentoring
	C4	• Levels of Authority and control (Power of authority) • Human errors and consequences • Data and facts-based decision making • Conditions of employment and code of conduct • Feasibility, Process capability, and Data analysis.
LC2	C5	• CRM: Customer Relationship Management • SLA (service level agreement) & Customer Satisfaction • Systems integration and big data. • Customer DGL development
	C6	• Vision, Mission, Values, and Purpose of the organization • Strategic analysis (long term, short term) and deployment • Objectives and targets setting • Product and process design and redesign • Data storage, handling, and analysis
LC3	C7	• External communication • Conflict management
	C8	• Safety, Health, and Environment • Behavioral Safety and human error • Autonomous and collaborative operational robots
	C9	• Value Stream Mapping • Scientific Problem Solving • Operational Simulations
	C10	• Continuous Improvement and Innovation • Reward and recognition
LL1	L1	• CRM: Customer Relationship Management • SLA (service level agreement) & Customer Satisfaction • Leader competence framework • Value Stream Mapping

(Continued)

Table 7: Continued.

Dim	Sub	Systems/skills/capabilities required
	L2	• Job descriptions • Skills assessment & training needs analysis
	L3	• Organizational Design and Organizational Charts • Internal Communication • Digitalization strategy.
LL2	L4	• Promotions and Job Grades assignment process • Performance Evaluation
	L5	• Leadership competence framework • Negotiation Skills • Difficult conversations and conflict management.
	L6	• Succession planning • Individual development plan. • Development and Coaching • Emotional Intelligence
	L7	• Skills assessment & training needs analysis • Leader competence framework
	L8	• Team design and performance • Data-based decisions. • Delegation of Authority.
	L9	• Target setting and performance evaluation. • Leading by example. • Motivational tools.
	L10	• Leadership versus Management • Development and Coaching
LL3	L11	• Process Management: Statistical control, In control and capable • Kata: Experimentation, testing, and trial. • Simulation techniques
	L12	• Innovation system (Continuous improvement, process improvements, and system innovation) • Waste elimination and value stream mapping
	L13	• Error proofing (Poka-yoke) • Human error: Progressive consequences system
	L14	• Design, operate, and improve processes (DA of Toyota) • Industry 4.0 tools design and implementation: Digitalization strategy.
	L15	• Scientific problem solving
	L16	• Shopfloor management • Daily Management system • Observation skills

(Continued)

Table 7: Continued.

Dim	Sub	Systems/skills/capabilities required
LL4	L17	• Strategy development (Hoshin Kanri) • Target setting • Rewards and Recognition program
	L18	• Strategy development (Hoshin Kanri) • Target setting
	L19	• Continuous flow (kanban, pull system line leveling, and balancing) • Process redesign (Toyota DNA)

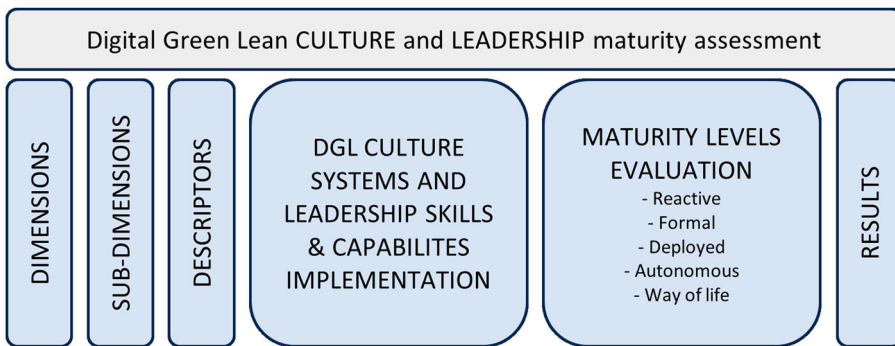


Figure 2. DGL culture & leadership maturity assessment.

This merger of systems coined Digital Green Lean, requires the company to gauge the integrated systems' various implementation levels and maturity. A complete business system design needs to be developed for DGL. However, to start with and to be aligned with the scholars, the first building blocks of the DGL implementation must be the company culture and leadership, proven to be the core of the Lean system in the literature. The rest of the tools or systems will be ad-hoc tailored to the organizational culture and leadership, following the same principles of efficiency and productivity.

Implementing Business Culture and Leadership skills must be measured, gauged, and improved. Therefore, we developed, not existing in literature as of December 2023, a maturity assessment that provides any organization with a tool to check both the level of advancement in implementing the different systems or skills required for DGL and points out the gaps paving the way for new implementations impacting the company's bottom line while ensuring sustainable digital practices across the organization.

This maturity assessment contributes to the literature by providing a tool that contains (1) three dimensions, ten subdimensions, and 38 systems for Business Culture and (2) four dimensions, 19 subdimensions, and 43 skills for Leadership that give the organization's maturity and progress. It is the starting point for designing an assessment model to guide the deployment of all DGL characteristics within the new industrial era. It also contributes practically to the organization by possibly performing the maturity assessment and getting insights, recommendations, and foresight to effectively manage the implementation of DGL culture and leadership.

Duarte (2023) suggests a ‘starting point for the design of an assessment model’. However, this paper proposes a full maturity assessment focused on the two main components of DGL: Company Culture and Leadership Skills.

This maturity assessment, prescriptive and comparative, will help manufacturing companies implement Industry 4.0 and Circular Economy, providing a systematic approach to evaluating the current cultural and leadership state, comparing it with other production centers, pinpointing areas for improvement, and strategically aligning the Lean initiatives with the evolving industrial landscape.

With this paper, the authors have tried to cover all areas of Culture and Leadership, using the existing literature and developing a novel maturity measuring system. However, some limitations to the research are required to be acknowledged. First, due to the final extension, this paper has not covered other operational dimensions and subdimensions, which are also very important for the business (e.g. value stream, process design, shopfloor design, financial aspects, scrap recycling, inventory management, remanufacturing, blockchain implementation, maintenance). Second, the tool’s efficacy still needs to be tested within an organization, implementing all concepts to check its validity. Future research should include a partial or comprehensive assessment of a manufacturing organization, contributing to the empirical validation of the assessment tool.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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ANNEX 1: Maturity Assessment Form Digital Green Lean Culture

Digital Green Lean dimension	DGL subdimension (Business culture)	Subdimension description and business expectations	Systems required	Maturity assessment				Way of life
				Reactive	Formal	Deployed	Autonomous	
Values and Principles	Human orientation, culture of respect	• The company is developing and implementing policies for equal opportunities, fairness, and employee care. It engages the employees to become asset protectors. Systems are in place to support this. • Company is human-centric: Autonomous robots are introduced to support operations. Employees only supervise. Humans are prioritized versus technology for low-physical intensity jobs. The impact of interconnectivity and robotization would be fairness, equal opportunities, and employee care. • The whole organization is focused on sustainability and conserving natural resources.	• Equal opportunities, fairness, employee care • Asset Management • Autonomous Robots strategy • Sustainability					
	Collectivism: In-group and institutional level of unionization	• Employees express pride, loyalty, and cohesiveness and collaborate for a better company. Organizational policies and practices encourage and reward teamwork and collective action through teams, committees, or any other form of unionism.	• Association of employees (internal and external) • National and local culture development					

ANNEX 1: Continued.

Digital Green Lean dimension	DGL subdimension (Business culture)	Subdimension description and business expectations	Systems required	Maturity assessment				Way of life
				Reactive	Formal	Deployed	Autonomous	
		• The company promotes the association of employees in different internal and external groups and measures benefits. (e.g. Formal teamworking, health committees, working groups with customers or suppliers, unionism, social responsibility committees ...) Teams are handled, and policies are drafted to control/support them. Employees become ambassadors of the company. National Culture impacts global or local policies, and it is measured. • Employee participates in operational decisions and SHE improvements. Consensus is reached for key operational innovations, including technology and process redesign for circularity. • The decentralized and agile decision-making process's impact is measured and improves teamwork. Technology and robotics are more variable. Circularity does not erode the team's cohesiveness and the leader's leadership style.	• Employee participation in company management • Team-working and robotization • Lean Manufacturing, Agile and Six Sigma • Leadership					

Power distance	• Organization design, spans of control, easiness of communication, and the degree to which members expect and agree that power should be unequally shared. • The systems to design organization structures and manning requirements, including robots, cobots, and other technology enhancements. Vertical and horizontal communication is embedded in the design of the organization. Employees accept the mandates by conviction and not by bureaucracy. The coaching policy is deployed and measured in the results.	• Organizational Design (Human, Robots, Cobots) • Internal Communication • Decision Making Levels • Training, development, coaching and mentoring
Authority distribution & decision-making, Uncertainty avoidance	• Personal authority distribution is done at all levels of the organization; there are control mechanisms to balance human/machine decisions, failure is tolerated, and consequences of failure are known. Employees strive to avoid uncertainty by relying on social norms, rituals, and standard practices to alleviate the unpredictability of future events. • There are controls to prevent biases, and the decisions are fact-based, removing tradition or intuition.	• Levels of Authority and control (Power of authority) • Human errors and consequences • Data and facts-based decision making • Conditions of employment and code of conduct

(Continued)

ANNEX 1: Continued.

Digital Green Lean dimension	DGL subdimension (Business culture)	Subdimension description and business expectations	Systems required	Maturity assessment				Way of life
				Reactive	Formal	Deployed	Autonomous	
		• Job insecurity is dealt with to avoid uncertainty of the future due to the introduction of new technologies or circularities. • By using big data, analytics, and integration online of the physical systems, the variability of the processes is reduced. There is a strategy for data-handling and decision-making considering technology output. • Recyclability and reuse to reduce material usage impact the process variation. The uncertainty and the decision-making policies contemplate it. A straightforward problem-solving process is in place. A strategy exists to eliminate and minimize or control uncertainty in any system or process. • There is a balance between Lean, I40, and sustainability in product and process development.	• Feasibility, Process capability and Data analysis.					
Customer Centric	Sustainable Customer Orientation	• The organization focuses the systems on sustainability and long-term customer relationships.	• CRM: Customer Relationship Management					

Performance orientation	• Customers engage in future-oriented policies such as planning, investing in the future, systems integration, and big data. • The organization builds long-term relationships with customers, including retention methods. • Organization handles the new type of customer: Moves from owning to leasing and impacts the circularity and productivity.	• SLA (service level agreement) & Customer Satisfaction • Systems integration and bid data. • Customer DGL development
	• The organization sets vision, mission, and values and converts them into long-term and short-term strategies for all aspects of the business, e.g. manufacturing, technology, and sustainability. It includes a strategy deployment system and measurement to track the implementation of the strategy. • Organization rewards group members for performance improvement. Employees are motivated to meet and exceed their personal and technical targets. There is a learning and development plan to train all employees in new skills coming from the strategy (e.g. new technologies, Industry 4.0, blockchain, data analytics,	• Vision, Mission, Values, and Purpose of the organization • Strategic analysis (long term, short term) and deployment • Objectives and targets setting • Product and process design and redesign • Data storage, handling, and analysis

(Continued)

ANNEX 1: Continued.

Digital Green Lean dimension	DGL subdimension (Business culture)	Subdimension description and business expectations	Systems required	Maturity assessment				Way of life
				Reactive	Formal	Deployed	Autonomous	
		cyber-physical systems, circularity, sustainability, waste, and recycling strategies) • Circularity includes Customer products and by-products. The impact of the reuse and higher recyclability is measured and reported for continuous improvement. Policies and systems are in place to deal with waste in the long term, targeting zero waste. • Inner and extended circle projects enhance operational performance and productivity and are built-in as part of the process design. Cloud computing: Data is stored in the cloud and interconnectable. • Data is integrated along the value stream for decision-making and process performance. Internet of Things, Analytics, and real-time data improve production performance in a learning organization.						
Operational Excellence	Receptiveness	• The company promotes social relationships with the community and other	• External communication					

	stakeholders. Digitalization of processes does not jeopardize the intent of clear communication. There is a process to deal with conflict. There are mechanisms to handle difficult situations and conflicts between employees, leaders, or areas. • There is no conflict between machines and humans; priority is given to human employees. Information, data, and analytics from technical systems are used in problem-solving and other innovation systems.	• Conflict management
Working conditions & SHE	• There are SHE, working conditions, and ergonomic policies and systems. They are communicated and implemented across the employees; they participate in making their jobs safer and healthier. The best available technologies are used to separate man-machine to minimize risks. There is a system to deal with human error in SHE-related topics. • There is a strategy to place autonomous robots in high-risk areas and cobots requiring high physical effort. The technology eliminates, minimizes, or controls	• Safety, Health and Environment • Behavioral Safety and human error • Autonomous and collaborative operational robots

(Continued)

ANNEX 1: Continued.

Digital Green Lean dimension	DGL subdimension (Business culture)	Subdimension description and business expectations	Systems required	Maturity assessment				Way of life
				Reactive	Formal	Deployed	Autonomous	
		SHE risks. Results are measured through data analytics of big data. • There are systems in place to minimize the impact of the circularity (e.g. increase of recycling, internal and external, longer cycles, more use of scrap, reusing policies ...). The employees are trained. • Redesign of operational processes, including inner circles and reviewing working conditions and SHE.						
	Problem solving culture (scientific method)	• The organization strives to eliminate non-value-added activities. Participating employees are trained and coached in problem-solving by leaders. Information technologies are used for data-based analysis and faster decision-making. • Production lines and cycles are constantly improved before digitalization to avoid automating the error. Simulations are done for every process or product redesign to optimize the improvement cycle and cost.	• Value Stream Mapping • Scientific Problem Solving • Operational Simulations					

Continuous
improvement &
innovation

- The Organizational mindset of everything can be improved. It is set in the policies and deployed to all employees. Innovation policies and systems are used by employee participation at all levels. Employees are recognized and rewarded for their collaboration on innovation and continuous improvement.
 - Innovation and continuous improvement culture include applying digital activities, new technologies, cyber-physical and security systems, sustainability policies, and process redesign to include circularities.
 - The operational redesign process includes circularity as a critical building block, extending the use of recycling materials as part of new operational processes (Cascade use)
- Continuous Improvement and Innovation
 - Reward and recognition

ANNEX 2: Maturity Assessment Form Digital Green Lean Leadership

Digital Green Lean dimension	DGL subdimension (Leadership)	Subdimension description and business expectations	Capabilities	Maturity Assessment				
				Reactive	Formal	Deployed	Autonomous	Way of life
Customer Oriented	Customer focus	• The company is focused on deliverables for internal and external customers. Customer needs are above individual or group needs. Customer targets are more important than individual targets. • External Customer processes are designed and integrated with Company data availability and analytics. • Leader competencies include customer focus, digitization, and sustainability to develop new digital circular processes for them. • Customer evolves into a data provider and becomes part of the production digital loop.	• CRM: Customer Relationship Management • SLA (service level agreement) & Customer Satisfaction • Leader competence framework • Value Stream Mapping					
	Customer & supplier development	• DGL is developed for customers and suppliers. Systems integration is in place to achieve higher levels of efficiency through process communication (IoT) improvement and waste elimination. • Leaders are capable, knowledgeable, and have tools to develop DGL in their internal and external Customers and Suppliers.	• Job descriptions • Skills assessment & training needs analysis					

		Leaders have clear role descriptions and authority.	
	Teamworking	• Leaders have straightforward organization and spans of control that guarantee employee coaching and development (ratio depends on the job complexity) • Leaders develop proper communication and transparency and have the social ability to make contacts. Robots are considered part of the team and an essential input for problem-solving and decision-making. • Leaders consider teams above individuals and design the organization structure with new technologies (e.g. IoT, AR, Big Data, Robots, system integration, cloud computing, cyber systems, sustainability, circularity, cascade use ...)	• Organizational Design and Organizational Charts • Internal Communication • Digitalization strategy.
Personal Development	Personal stability	• There is a promotion policy, including horizontal promotions. Each position has minimum skills and stability to gain expertise and coaching. • Leader's evaluation system is based on soft skills, personal development, and hard skills. There is a skill-development matrix for leaders.	• Promotions and Job Grades assignment process • Performance Evaluation
	Personal behavior	• Company culture is embedded in the daily work of the leader, creating role models.	• Leadership competence framework

(Continued)

ANNEX 2: Continued.

Digital Green Lean dimension	DGL subdimension (Leadership)	Subdimension description and business expectations	Capabilities	Maturity Assessment				
				Reactive	Formal	Deployed	Autonomous	Way of life
		• Servant leadership style includes hansei (self-reflection), self-awareness, and assessment. Modesty & humility. Empathy. Credibility. Leaders promote professional relationships with the employees and are accessible. • The implementation of new technologies is done with collaboration and consensus with the team and puts the company's benefits above individual or team objectives. • Company leaders are experts in leading difficult conversations and managing conflict.	• Negotiation Skills • Difficult conversations and conflict management.					
	Human-centric	• The organization has a succession plan process attached to an individual development plan. • Leader constantly develops and coaches his successor and the team. • Leader handles the digitalization strategy and sustainability effort with emotional intelligence and ethics	• Succession planning • Individual development plan. • Development and coaching					
	Self-developing and learning	• Constant self-development and learning in a structured way, guided	• Skills assessment & training needs analysis					

	by a coach using available technologies (AR, digital twins ...)	• Leader competence framework
	• There is a specific leadership skills and competencies development plan. It includes social/personal/technical skills, new technologies (augmented reality, robotics, simulations ...), sustainability, and inner/longer circularity principles.	
Empowerment	• The company promotes team empowerment and fact-based decisions after data gathering and analysis. • Delegation of authority and accountability systems in place, measured and effective. Facts are separated from opinions for decision-making. • Data is shared across and not individual property. Autonomous robots, deep learning, and other systems provide data to the organization where/when it is needed or on demand.	• Team design and performance • Data based decisions. • Delegation of Authority.
Self-transcendence	• Leaders set the true north and strive for perfection by visualizing greatness (self-transcendence). Leaders have physical and psychological strength and understand their contribution to the organization's future and influence on employees' personal and social lives. • Leaders are allowed and willing to	• Target setting and performance evaluation. • Leading by example. • Motivational tools.

(Continued)

ANNEX 2: Continued.

Digital Green Lean dimension	DGL subdimension (Leadership)	Subdimension description and business expectations	Capabilities	Maturity Assessment				
				Reactive	Formal	Deployed	Autonomous	Way of life
		take challenges with implementing new technologies and are not afraid of consequences. • Their critical role in the organization is reinforced and empowered. (self-esteem, self-transcendence, and motivation).						
	Servant	• Leaders follow the servant model and are encouraged to be humble, trustful, listen to others, respectful, and fair. • Leaders use the new technologies development and sustainability principles to teach and develop their teams. (AR, Digital Twins, robots ...)	• Leadership versus Management • Development and coaching					
Lean Principles	Experimental	• Leaders use data analysis, experimentation, hypothesis testing, and trial (Kata): Standardizing the results, communicating the improvements, and recognizing the employees. • New technologies enhance performance and increase productivity by designing experiments, simulations, big data, deep learning, artificial	• Process Management: Statistical process control, In control and capable • Kata: Experimentation, testing and trial. • Simulation techniques					

	intelligence, or other suitable technologies.	
	• Leaders balance technology implementation and sustainability to get the best for the organization.	
Continuous improvement and innovation	• Organization promotes disciplined CI and Innovation through critical thinking, intellectual stimulation, and risk management. • System design includes new technologies (e.g. IoT, Big data and analytics, robots, simulations, cyber systems, and 3D manufacturing) and Circularity as critical elements. Results are more efficiency, less waste, higher productivity, and employees more engaged.	• Innovation system (Continuous improvement, process improvements and system innovation) • Waste elimination and value stream mapping
Zero-defects	• There is a zero-defect mindset and tolerance for mistakes and failure when they happen. • Human error is dealt with based on intentionality and consequences through a progressive consequences policy. Learning is captured when mistakes happen. • There is a process to handle variability and error produced by the autonomous robots connected (IoT) and the consequences implemented.	• Error proofing (Poka-yoke) • Human error: Progressive consequences system
Process and lean expertise	• There is a process and knowledge to design, implement, and improve	• Design, operate and improve of processes (DA of Toyota)

(Continued)

ANNEX 2: Continued.

Digital Green Lean dimension	DGL subdimension (Leadership)	Subdimension description and business expectations	Capabilities	Maturity Assessment				
				Reactive	Formal	Deployed	Autonomous	Way of life
		flow, takt time, and standardize work. • Leaders use augmented reality, big data, deep learning, artificial intelligence, robots, and other technology to support lean principles and improve process design, including circularities, sustainability, and productivity.	• Industry 4.0 tools design and implementation: Digitalization strategy.					
	Problem-solving	• Leader masters scientific problem-solving, data analysis, root cause analysis, and simulation as a way of thinking. Teaches and guides others. • Information technologies are used for data analysis and decision-making. Production lines, robots, and cycles are connected (IoT), integrated, and constantly improved. To optimize the improvement cycle and cost, deep learning and simulations occur for every process/product redesign.	• Scientific problem solving					
	Genchi genbutsu	• Leaders are constantly on the shop floor as a philosophy for data-gathering, understanding the situation, circularity status, and	• Shopfloor management • Daily Management system					

		coaching. Visual management and digital data visualization are key facilitators. • Data gathering implementation is done where the data is needed, avoiding central data controls as much as possible. A daily management system requires augmented reality, simulations, and deep learning (AI). • Observation skills
Performance Driven	Target setting	• There is a system to communicate its vision, mission, and values as long-term and short-term targets using digital information and quick data access. Targets for AI and autonomous robots are set separately and are part of the leader's responsibility. • Leaders recognize and reward achievements in real-time on the shop floor. • Strategy development (Hoshin Kanri) • Target setting • Rewards and Recognition program
	Targets deployment	• Consistent and transparent target deployment and tracking (Hoshin Kanri). Reward and recognize success. • Autonomous robots, deep learning, AI, circularity, cascade use, and other new processes implemented are included in those targets. Responsibility for the outcome stays with the process owner. • Strategy development (Hoshin Kanri) • Target setting
	Flow	• Leaders understand and use flow, system integration, stability, • Continuous flow (kanban,

(Continued)

Digital Green Lean dimension	DGL subdimension (Leadership)	Subdimension description and business expectations	Capabilities	Maturity Assessment				Way of life
				Reactive	Formal	Deployed	Autonomous	
		leveling, balancing, and inner and extended circles concepts. Manage flow rather than isolated operations with available tools like AR, Big data, cloud computing, simulation, deep learning, or digital twins. • Leaders improve processes from linear design to circular flow, where possible, using all the new technologies and tools and ensuring productivity and sustainability are maintained.	pull system line leveling and balancing) • Process redesign (Toyota DNA)					