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Deriving essential components of lean and industry 4.0 assessment model for manufacturing SMEs

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Abstract

Quantifying lean and ICT architecture related to Industry 4.0 is a new challenge in Small and Medium Scale Enterprises (SMEs) that needs to be addressed by both research as well as enterprises themselves. Especially in the manufacturing sector, SMEs need to transform themselves into emerging trends such as industry 4.0 while practicing existing manufacturing philosophies such as Lean Production Systems (LPS) to be competitive in global markets. The major concern is that there are many assessment models available to measure the status of an enterprise related to either LPS or Industry 4.0. Often, these models are complex and don't fulfill the requirements of manufacturing SMEs. On the other hand, most of the models only consider either lean or industry 4.0 elements. The outcomes of this research help to develop a hybrid model including both lean and industry 4.0 features suitable for manufacturing SMEs. The main objective of this research is to provide state of the art literature on existing assessment models and consequently map lean and industry 4.0 components to the specific characteristics of manufacturing SMEs. The paper concludes with a summary and outlook for our future research.

Keywords: Industry 4.0; lean; maturity model; self-assessment tool; digital transformation

1. Introduction

Digitalization is rapidly changing the manufacturing landscape both in large industries as well as in SMEs. Manufacturing companies are at the forefront of this ubiquitous technological adaptation to enhance and optimize their manufacturing processes [1,2]. Digitalization concerns complete value chain of the enterprise but not specific domains such as Information Technology (IT) or production.

In manufacturing SMEs, the biggest challenge is to identify applications of industry 4.0 (from now on, I4.0) in their processes and initiate measures to adopt digital solutions. On the other hand, for last few decades, companies have evolved through a learning process and established standardized production processes such as Lean Production Systems (from now on, LPS) [3] or any other best practices suited for their manufacturing. Therefore, it is essential to assess current situation and identify opportunities to introduce digital solutions. In recent decades, most of the European companies are characterized by LPS [4] that means any digital adaptation affects existing production systems, for example LPS. In this regard, a hybrid maturity model that combines lean and I4.0 for assessment is more attractive than assessment models that only considers either lean or I4.0.

Computerization and connectivity are prerequisites for implementing I4.0, this means all the processes of a company are connected and cross-departmental information sharing is possible [5]. In general, realizing a complete lean and digital organization is still a vision for many companies, especially manufacturing SMEs. There are many components that can be assessed in manufacturing SMEs, which will result in an exhaustive and complex model. Therefore, it is important to recognize essential components that have an effect on the entire value chain of manufacturing SMEs, which brings up the following research question for our research.

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RQ: What are the essential components of a manufacturing SME to assess its present status of lean and industry 4.0?

This paper first discusses the specific characteristics of a manufacturing SME, briefly presents lean and I4.0 before extensively reviewing the existing assessment/ maturity models and their advantages and disadvantages. In chapter 3, methodology for this research is discussed and mapping between lean and I4.0 with specific characteristics of a manufacturing SME are presented. The paper concludes with a summery and future work.

1.1. Characteristics of a manufacturing SME

There is a dilemma/debate on how to distinguish small and medium companies with larger companies. In European Union (EU), there are specific, quantifiable boundaries to define an enterprise in the category of an SME. Table 1. illustrates what constitute an SME [6].

Table 1. Specifications of an SME.

Enterprise	Number of employees	Annual turnover
Small	<50	≤ € 10 million
Medium	<250	≤ € 50 million

One main reason behind the existence of SMEs is their **strategy** to produce customized **products** to customers or large manufacturers [7]. Agile product innovation is a key characteristic of any SME to sustain their business and find markets in new business sectors. However, in general, SMEs are financially restrained [8] and therefore, they use general-purpose machines [9] and believe in their hard work to produce customized products rather than adopting advanced manufacturing technologies. Large manufacturing companies have organizational advantages, combined with focus on new **technology** for manufacturing, Information and Communication Technology (ICT) and predictive data analytics wherever necessary. These technological and ICT integrations are very challenging for manufacturing SMEs because of their financial restraints and traditional approaches. To meet variance and fluctuations in **customer** demands, SMEs maintain a close relationship with their customers [10].

In the dimension of **operations**, most SMEs lack awareness of standards [11], simulation, and decentralization of processes, as well as interdepartmental and interdisciplinary collaborations [12]. This is due to the amount of resources and skills required to fulfil those requirements. Often, manufacturing SMEs stock a large amount of resources to avoid inventory shortages in production in case of variation of market demand [12]. Related to **leadership**, decision making related to production, products, machinery, and policies are based on experience of the employees and instinct of top management instead of new trends in the global market, forecasting future demands etc. [10]. SMEs generally have a specific number of **suppliers** to procure resources and eventually they become extremely dependent on them as their supplier network is not very strong [13]. For any company, organizational aspects such as **culture** and **employees** are critical entities of success. In SMEs, the employees are often trained in diverse qualifications to fulfill rapidly changing market requirements [12] but they lack mentoring, targeted individual training and supervising [14]. On the other hand, in most SMEs organizational culture is not very flexible this hinders open innovation in respective enterprises [15,16]. Table 2. presents the characteristics of a manufacturing SME and their respective company dimension.

Table 2. Characteristics of a manufacturing SME and their respective dimension..

Ability to produce customized products [7]	• Products • Strategy
Lack of up to date ICT integration [16]	• Technology
Lack of advanced manufacturing technologies (AMT) [9]	• Technology
A close relationship with customers [10]	• Customers
Lack of awareness of standards and decentralization of processes, as well as interdepartmental and interdisciplinary collaborations. & excess storage [11,12]	• Operations
Knowledge gap in strategic decision making [10]	• Leadership
Lack of a strong collaborative network [13]	• Suppliers
Diverse qualification of employees &lack of mentoring, targeted individual training and supervision [12,14]	• Employees
Resistance to change, lack of open innovation culture & lack of flexible organizational culture [15,16]	• Culture

2. Lean Production System and Industry 4.0

2.1. Lean Production Systems (LPS)

The primary goal of Toyota Production System (TPS) later known as LPS is to reduce operating costs by eliminating all non-value adding entities (waste/muda) from the value chain of the company [17]. In LPS the customer-centric aspects such as best quality, short lead-time, and lower costs are key focus areas. These are achieved by a set of methods and tools such as Just-in-Time (JIT), jidoka (autonomation) and heijunka (production levelling) etc. In manufacturing SMEs, there is an intrinsic resistance to commit to the change when things are going well [18] and therefore, such companies fail to see the benefits of lean initiatives. On the other hand, lack of financial resources and technical expertise in manufacturing SMEs can hinder the implementation of LPS [19].

2.2. Industry 4.0 (I4.0)

There is no unanimously agreed definition of I4.0 but two of the most commonly used definitions are presented here. In socio-technical perspective., According to [20], I4.0 means “the networking of people and things and the convergence of the real and virtual worlds that are enabled by Information and Communication Technology (ICT)”. In technical terms [21], “Industry 4.0 is defined as digitization of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous cyber-physical systems (CPS), and analysis of all relevant data”.

Increasing use of ICT in manufacturing sector brings opportunities in the industry that are currently not realized. For example, integrated factories or smart factories [22] enabled by

CPS can manage more complexity to produce customized products, helps in optimized decision-making etc. CPS integrates cyber world (software, cloud computing, data analytics) with the physical world (machines, processes, production, logistics and marketing). Current research [4,22] suggests three major technological dimensions in I4.0;

- Horizontal integration of the entire supply chain
- Vertical integration of organizational operations
- End-to-end engineering across the entire value chain

Horizontal integration concerns the idea of integrating various IT systems in and beyond the manufacturing company's boundaries. For example, manufacturing relevant data is integrated into supplier's network to ensure availability of stock at all the times. On the contrary, vertical integration deals with the integration of IT systems in different hierarchical levels in the company. For example, sensor data from machines on the manufacturing level is integrated into the company's corporate planning for data-driven decision-making. End-to-end engineering concerns with the product life cycle from manufacturing, usage and until the end of its life. All the data gathered throughout the life cycle is connected end-to-end [23].

3. Existing assessment and maturity models of Lean and Industry 4.0

According to the Oxford dictionary, assessment refers to "the action of assessing someone or something" and to assess means "Evaluate or estimate the nature, ability, or quality of.." [24]. On the other hand, maturity is "state of being complete, perfect, or ready" [24]. In general, assessment models or maturity models can be used as an effective tool to measure the ability of an organization or a process. The results are then used to set-up a roadmap for the desired future state of the organization or process. To capture the as-it-is state in organizations qualitative and quantitative studies are recommended in the literature [25] along with academic and industrial expertise.

Researchers are actively publishing industry-specific assessment or maturity models for example, in lean manufacturing [26], and in industry 4.0 [5,27–31]. The following section presents the existing lean and industry 4.0 assessment/ maturity models.

3.1. LESAT: The Lean Enterprise Self – Assessment Tool

The "Lean Enterprise Self – Assessment (LESAT)" [26] developed in MIT is targeted at enterprise leadership team to support both "as-is" (current state) and "to-be" (desired state) states of the organization concerning lean manufacturing. LESAT considers three major dimensions of an enterprise such as lean transformation/ leadership, life cycle processes, and enabling infrastructure processes with 54 lean enterprise practices. Each practice is assessed from level 1 to level 5 along with a maturity matrix assessment sheet. LESAT is a comprehensive, detailed and action-oriented tool that presents the gaps and roadmap to reach the desired level of maturity. Furthermore, the first LESAT version was published in 2002, therefore, the later innovations such as big data, industry 4.0 are not considered in the assessment model. The tool is developed in the view of leadership of large companies and with regards to SMEs this tool is complex and time-consuming.

3.2. Industry 4.0 Maturity Index

"Industry 4.0 maturity index" by Acatech [5] presents a systematic process to evaluate the company's as-is status and progressing steps to achieve the desired state in terms of digitalization. Their methodology includes identifying the gaps between current and desired state by gap analysis and introducing missing capabilities to attain desired benefits. In the end, a digital roadmap presents the evolutionary steps towards the desired state. Deployment of industry 4.0 requires significant upgrades to the company's current digital infrastructure, capabilities, and competencies that can take several years. Therefore, the company in transition needs a long-term vision. Acatech's maturity model identifies computerization and connectivity as the prerequisites for industry 4.0. Further steps in digital transition includes visibility, transparency, predictive capacity, and adaptability.

Even though the study is designed specifically for manufacturing companies, a section dedicated to LPS or existing production systems is missing. Model is also missing the perspectives concerning SMEs.

3.3. SIMMI 4.0

"SIMMI" (System Integration Maturity Model for Industry 4.0) [28] focuses on IT system landscape in a company. Their maturity model consists of five stages and detailed information about each stage so that the companies can assess themselves. Recommendations are mentioned at each level to attain the next level of maturity. The model is very simple to understand with a focus on IT landscape in SMEs but for the assessment of manufacturing systems in and beyond enterprise borders, there should be a holistic study including lean and digital features.

3.4. Industry 4.0 Quick CheckUp

In "Industry 4.0 Qucik CheckUp" [29], before the development of the tool, the needs of SMEs with respect to digital requirements are analyzed based on testing two popular assessment models of Industry 4.0. These requirements for SMEs are evaluated against five existing models with representatives from SMEs. The study concludes that none of the existing models meets the requirements of SMEs. Therefore, a method has been developed to meet the requirements of SMEs. In this model, five dimensions of SMEs such as business management, development, manufacturing, supply chain, and services are considered with 17 items all together. A questionnaire is used to collect the data to find the current state of the company under assessment and suggests future digital integration steps.

The model is simple and suitable for assessing SMEs. Major aspects of lean such as key performance indicators, production leveling etc. are missing and there is little focus on I4.0 concepts such as horizontal and vertical integration, cloud applications etc. in the model.

3.5. The VDMA Guideline Industry 4.0

"Guideline industry 4.0" developed by VDMA and their partners in Germany aims to provide German SMEs on how to implement new industry 4.0 business models and provide support throughout the implementation phase. It includes five stages of preparation, a phase of analysis and creativity, evaluation, implementation [27]. Guidelines provided in the model are tested and validated for practicability and applicability to SMEs. The program design by VDMA is a holistic approach towards the digital future with assessment being one of the phases of the total transition. The value of I4.0 depends on developing new products, processes and business models and utilizing the combined benefits of existing technologies.

The "Tool box Industry 4.0" is used in assessing the maturity of a company in two categories products and production each of them has six modules. The toolbox is very technical in nature and it didn't consider the other important organizational aspects such as strategy and personnel. This model also lacks open source access where SMEs can autonomously test their maturity level concerning I4.0. On the other hand, components of the toolbox are broken down into feasible development stages which in general is the interest of SMEs. The final two phases of the guidelines, evaluation, and creativity exclusively considered internal and external competence to realize desired goals at an affordable cost.

3.6. Industry 4.0 Maturity Model

Fraunhofer Austria Research together with Vienna University of Technology developed a maturity model assessing I4.0 readiness [30] with the scope of extending dominating technology focused maturity models by adding organizational aspects to it. The focus is on manufacturing enterprises with overall 62 aspects that are classified into nine dimensions: products, customers, operations, technology, strategy, leadership, governance, culture, and people. The model has been tested and validated in many enterprises, but it is not available as an open source tool for companies anonymously to test their status of digitalization. The major advantage of this model is their methodological approach to analyze data using the importance of each aspect rated by experts as a weighing factor. The model didn't address the lean aspects as well as identification of improvement opportunities or roadmap for further developments. Furthermore, an SME perspective is also missing from the model.

3.7. Production Assessment 4.0

Developed by Fraunhofer IAO, Production Assessment 4.0 [31] enables the recording of lean management principles that already exist in the manufacturing companies and presents the practical answers to the evolutionary vision of I4.0 with feasible and customized migration plans. This model consists of five strategic areas of manufacturing companies such as strategy, process and value stream, organization, methods and tools, and personnel with different aspects under each area. The assessment methodology includes a two-stage process, in the first stage, each area and aspects of the company are evaluated based on skill scale from skill level 1 to skill level 4. The second stage enables the necessary differentiation of skill classification and derives a migration path to I4.0. The model emphasizes the importance of lean management in a successful transition to I4.0. The model visualizes lean management as the prerequisite to achieve higher levels such as I4.0 fundamentals and I4.0 excellence. The model is suitable for SMEs that considered both existing manufacturing systems and visionary I4.0 features. The model needs simplification as the technical terminology used in it is difficult to comprehend at times.

4. Methodology

To answer the research question framed in section 1 we developed a systematic methodology majorly based on Becker's step-by-step process for development of maturity models [32]. The scope of this paper is limited to deriving essential components of manufacturing SMEs to assess their present status of Lean and I4.0. Therefore, the above said methodology has been partially applied.

In step 1, existing literature on SMEs is comprehensively reviewed to understand the specific characteristics of a manufacturing SME. Each characteristic is allocated to a dimension of the industry and in total nine major dimensions are considered (Table 2.).

In the next step, an extensive review on fundamentals of LPS, I4.0, smart manufacturing, lean maturity models, I4.0 maturity models and related terms such as assessment and readiness models was conducted. Google scholar, university library system and bibliography in review papers are the sources for most of the literature considered in this paper. Only relevant literature is presented in order to avoid the redundancies from already published review papers. The key focus of the literature review is to find research gaps and the suitability of each maturity model for a manufacturing SME that can help SMEs to assess their present state in the transformation to LPS or I4.0.

In the final step, the essential components of lean and industry 4.0 are mapped to the characteristics of a manufacturing SME.

5. Essential components of Lean and Industry 4.0 assessment models for a manufacturing SME

In this section, the research gaps in the existing assessment models have been derived in a manufacturing SME perspective. One major concern is that these assessment models are developed to facilitate the needs of large manufacturers in terms of I4.0. This is because large companies hugely support the prime research in this field. The other research gap is the exclusion of existing manufacturing systems such as LPS and targeted focus on I4.0, ICT, and AMT. Some maturity models considered the socio-technical aspects of I4.0 as it can enable new business models, for example, data-driven services and processes that can change the way employees communicate with machines on the shop floor. Finally, these assessment models failed to mention the future framework after the assessment. However, the last research gap is not true for all assessment models that are explained in section 2.

In this paper, in order to facilitate research gap 1 and 2, we derived the essential components of lean and I4.0 and mapped them with the specific characteristic of a manufacturing SME. This mapping helps researchers to develop a hybrid assessment model for manufacturing SMEs that covers both aspects of LPS and I4.0. Table 3. presents the mapping of specific characteristics of a manufacturing SME with lean and I4.0 components.

To produce customized products meaning to be able to respond quickly to customer demands regarding physical dimensions of the product and material combination etc. Lean tools such as Single-Minute Exchange of Dies (SMED) advocates setup time reduction and enhances manufacturing flexibility. On the other hand, the culture of continuous improvements (kaizen) ensures best practices are being applied while manufacturing a product. Production leveling (heijunka) reduces the variability of arriving jobs so that unnecessary changeover of machines can be avoided to get maximum value from the process. Therefore, the combination of SMED, kaizen and heijunka can supplement product customization in a manufacturing SME. Moreover, simulation tools and smart facilities (e.g. 3D printing) can be effectively deployed as prototyping tools before the actual product is manufactured to avoid the risk of product failure.

The authors believe that advanced ICT technologies can help manufacturing SMEs to integrate suppliers and customers with operations of the enterprise to improve existing relationships, new collaborations etc. This claim needs an empirical evidence that will be tackled in our future research. Big industries and research institutions are adopting Augmented Reality (AR), Industrial mobile devices etc. to improve communication between human and machines on the shop floor for various applications such as assembly, quality assurance, and maintenance etc. [33]. Lean tools such as Value Stream Mapping (VSM), Key Performance Indicators (KPIs) and Material Replenishment are proven as effective tools to tackle issues related to the elimination of excess storage, strategic decision making etc.

Qualification and Skills are important aspects to implement and sustain lean and especially Industry 4.0 tools [34]. To excel and get value from these new adaptations, SMEs need to train their employees in specific skills such as 5S, quality, sensors, and data analytics etc.

Table 3. Mapping of a manufacturing SME characteristic with lean and I4.0 components.

Characteristic of an SME	Lean and I4.0 components
Ability to produce customized products [7]	Lean components: • Reduction of change over time (SMED) • Continuous improvements (kaizen) • Production levelling (heijunka) I4.0 components: • Simulation models • Smart facilities
Lack of up to date ICT integration [16]	I4.0 components: • Vertical integration of the company-wide network. For example, Enterprise Resource Planning (ERP) and Collaborative Planning, Forecasting and Replenishment (CPFR)
Lack of advanced manufacturing technologies (AMT) [9]	I4.0 components: • Machine to machine communication • Human to machine interface
A close relationship with customers [10]	Lean components: • Value Stream Mapping (VSM) I4.0 components: • Horizontal integration of value networks. For example: ICT infrastructure for scheduling and controlling external logistics
Lack of awareness of standards and decentralization of processes, as well as interdepartmental and interdisciplinary collaborations. & Excess storage [11,12]	Lean components: • Material replenishment, VSM, and standardization I4.0 components: • Horizontal and vertical integration of all the socio-technical systems in the company
Knowledge gap in strategic decision making [10]	Lean components: • Key Performance Indicators (KPIs) • Strategic planning and implementation of lean tools I4.0 components: • Big data analytics of decision making • Strategic planning and implementation of digital tools
Lack of a strong collaborative network [13]	Lean components: • Multiple suppliers I4.0 components: • Horizontal integration of value networks
Diverse qualification of employees & lack of mentoring, targeted individual training and supervision [12,14]	Lean components: • Training on lean tools such as 5S, quality and standardization I4.0 components: • Training on smart sensors, digital technologies, and data analytics etc.
Resistance to change, Lack of open innovation culture & Lack of flexible organizational culture [15,16]	These specific characteristics hinders the transformation towards lean and I4.0 in a manufacturing SME. Therefore, management needs a long-term holistic transformation plan of above-mentioned dimensions.

6. Summary and Future work

This research work aimed at mapping essential components of lean and industry 4.0 with the specific characteristics of a manufacturing SME. Moreover, the mapping should help researchers to develop a hybrid assessment model that includes both existing manufacturing systems such as lean and emerging advanced technologies in ICT known as industry 4.0.

The paper begins with deriving specific characteristics of a manufacturing SME and discusses the fundamentals of Lean Production Systems and Industry 4.0. We have defined a guiding research question that was answered through literature review and mapping the components of lean and industry 4.0 with specific characteristics of an SME. Research gaps in the existing literature are presented based on the missing perspectives concerning manufacturing SMEs.

Based on this research and mapping shown in table 3, further research aims to develop a self-assessment model that addresses research gaps in the existing literature, 1. to facilitate manufacturing SME perspective in the model, and 2. to include both aspects of lean and industry 4.0. A self-assessment model consists of a set of quantitative questions related to major dimensions of a manufacturing SME identified in this research. The responses to the quantitative questions then analyzed and the results of the analysis are visualized in the form of radar charts for easy understanding.

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