Prioritization of Industry 4.0 Technologies to Increase Maturity in Lean Manufacturing from the Perspective of Enterprise Interoperability

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Abstract. In face of the deep changes in the global industrial scenario stemming from the concepts of Industry 4.0 and Lean Manufacturing philosophy, the adoption of new priority technologies associated with these concepts ensure that a company is permanently competitive in the market. The main goal of this article is the construction of diagnostic and decisional evaluation models, in the Lean Manufacturing domain and from the perspective of interoperability, for prioritizing the adoption of Industry 4.0 technologies, and using multi-criteria decision-making methods (MCDM) as support. For the diagnostic evaluation, a hybrid approach of the AHP and DEMATEL multi-criteria methods was carried out, using the Lean Manufacturing elements as criteria for the decisional evaluation. From the AHP result, the criteria diagnosed as fragile were selected and subsequently applied in DEMATEL, a method that allows the evaluation of the influences generated between the criteria. The aggregation of the weight structure resulting from the AHP and Dematel methods allows the characterization of the diagnostic weighting to define the weights of the PROMETHEE II decision matrix, guiding the prioritization of alternatives, i.e. technologies of Industry 4.0. The approach was applied in a company of the metal mechanic sector, and the results indicated that Enterprise Resource Planning (ERP) integrated with Business Analytics (BA) was ranked as the technology that should be implemented with priority to raise the level of organizational maturity on Lean Manufacturing. The integration of these concepts offers several advantages for the organization such as waste reduction, continuous improvement support (Kaizen), and information sharing.

Keywords: Lean Manufacturing · Industry 4.0 · MCDM · Interoperability

1 Introduction

With the increasing competition in the industrial sector fostered by the Fourth Industrial Revolution, many organizations are aiming to fulfill the customer needs by means of

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the Lean Manufacturing philosophy, which has stood out over the past 60 years as a highly efficient production system. However, the Lean Manufacturing management model serves as the foundation for the implementation of Industry 4.0 in the organizations [1].

The Fourth Industrial Revolution, or Industry 4.0 (I4.0), arose in Germany in 2011 with the need to foster competition among the German manufacturers resulting from the introduction of Cyber-physical Systems and the Internet of Things. The industry 4.0 main principle lies in the fact that by connecting machines, systems, and assets, companies can build smart networks and, then, autonomously control the production modules [2]. In its turn, the consolidation of the Toyota Production System (TPS), later defined as Lean Manufacturing (LM), takes place through a set of practices interconnected with each of its pillars: visual management, standardized work, production leveling, waste elimination, teamwork, just-in-time, and jidoka [3]. To achieve that, a closer integration among industrial entities and processes is needed, as demanded by the Industry 4.0 technologies.

The evolution of information and communication systems follows business trends aligned with an organizational and operational management that is dynamic, flexible, and adaptable to the business plan, considering both intra- and inter-organizational interaction as a success factor [4]. A way to evaluate the attributes related to the collaboration environment, the communication capability among entities, and the level of information sharing among companies resides in the concepts of Interoperability. With regard to Industry 4.0, Interoperability is associated with the ability of cyber-physical systems, humans, and factories to effectively communicate over the Internet of Things and other related technologies [5].

When it comes to lean production, the Industry 4.0 technological concepts and enablers are crucial for the continuous improvement, and when integrated through efficiency and productivity breakthroughs for a joint performance, the I4.0 and LM systems can promote several benefits. The I4.0 and LM models can provide mutual support, since Industry 4.0 technologies can help eliminate the barriers to the Lean Manufacturing implementation, while the production environments already immersed in the Lean Manufacturing culture are more willing to be modeled and controlled by an Industry 4.0 platform [6].

Given the several technologies available to carry out improvements in the industrial sector, and thus promote an increasing maturity level, the prioritization of implementation actions of I4.0 technological enablers for organizational and maturity performance improvement (LM) is required. Such prioritization must take evaluation perspectives of the enterprise interoperability (EI) into account [7].

The main objective of this work resides in the proposal of a diagnostic approach to Lean Manufacturing under the interoperability perspective and based on multi-criteria decision-making methods (MCDM) in order to support the implementation prioritization of Industry 4.0 technologies under a decisional approach.

2 Literature Review

Lean Manufacturing emerged in the 1950s with the need for high productivity rates at lower costs linked to greater customer participation along the supply chains and reduction of operations that do not add value to the product [8]. Industry 4.0 is based on the integration of information and communication technologies that allow reaching new levels of productivity, flexibility, quality and management, enabling the generation of new strategies and business models for the industry, being, therefore, considered the Fourth Industrial Revolution [9].

The literature review revealed that, since 2014, there have been well-referenced articles dealing with the LM-I4.0 relation. Among them, the article [10] stands out as it contains a literature review that aims to evaluate how the emerging disruptive technologies can improve the lean practices as well as analyze their impacts and benefits for the organizations that are moving towards this new industrial paradigm.

The present work comprises a literature review with the Lean Manufacturing and Industry 4.0 dimensions. The objective of this section consists in obtaining the Lean Manufacturing principles and the Industry 4.0 technologies to be selected for the diagnostic assessment as well as determining the correlation between these concepts so that they are used in the decisional assessment.

In the literature, it is possible to find some correlation models between Lean Manufacturing and Industry 4.0 principles. But, there is not a quantitative approach for the assessment and prioritization of Industry 4.0 technologies, aiming to increase the organizational maturity in relation to the Lean and considering the Interoperability perspectives and barriers. Such analysis is crucial for companies that have just launched themselves on the digital revolution trajectory, once it provides support to the decision-making on which capability must be implemented with priority so as to maximize the lean manufacturing.

3 Framework

As presented in Fig. 1, the development of this methodology is composed of three main steps: usability filtering of the Lean Manufacturing principles and Industry 4.0 technologies, diagnostic assessment, and decisional assessment.

In face of the large amount of existing pillars and technologies, and their different implementation complexity levels, it is crucial that the usability filters are applied so that concepts that can be supported by the company are used in the assessment. The first filter is called LIM matrix (Lean Interoperability Matrix) and evaluates the interoperability perspectives according to the FEI model in [11] (business, processes, services, and data) and its barriers (organizational, semantic, and technological) based on the Lean Manufacturing principles, assigning values according to the importance level of the criteria in the scenario under analysis. The second filter is called IPM matrix (Industry 4.0 Performance Matrix). This method considers the Industry 4.0 technologies and the five performance indicators proposed by [12] (Reliability, Cost, Flexibility, Quality, and Readiness). As a result, the interconnection between the Lean pillars and the Industry 4.0 technologies through the decisional method, the model will be taking into account the

elements with potential to be integrated with other systems, in addition to considering the organizational maturity level.

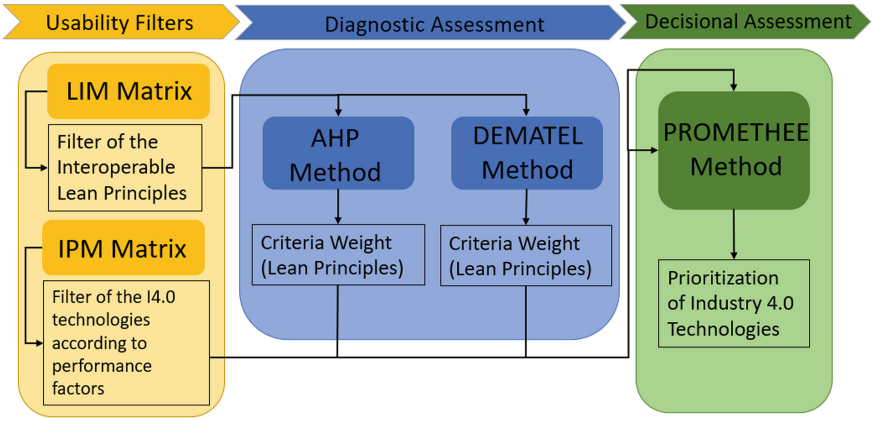

Fig. 1. Framework stages.

3.1 Diagnostic Evaluations

The diagnostic assessment stage made use of the AHP and DEMATEL multi-criteria methods, which will provide the weights to be assigned to the criteria in the decisional assessment. The combined use of these methods maximizes the diagnostic of the case, since the AHP method evaluates and quantifies the criteria importance, while the DEMATEL method proposes an approach focused on the intensity of the connections among criteria. The use of these diagnostic approaches, mainly the AHP method, is inspired by well-referenced works from the Industrial and Systems Engineering Graduate Program (PPGEPS), which explore the due relevance and contribution of such methods to assessment processes.

3.1.1 AHP (*Analytic Hierarchy Process*)

After determining all Lean Manufacturing criteria deriving from the LIM matrix, the AHP multi-criteria method was conducted. Besides supporting the definition of the criteria level of importance, the use of this method also enables the analysis of which criteria (Lean Manufacturing principles) are being fulfilled, i.e. those to which the company is paying more attention and those that are unsheltered, and thus more fragile. Under the AHP hierarchical structure, the Interoperability dimensions were used as criteria and its barriers as sub-criteria, and to which the LM elements were added. Such elements, in their turn, are associated with the method alternatives, indicating at which level the company is in relation to the Lean tools. The structure of the method is presented in Fig. 2.

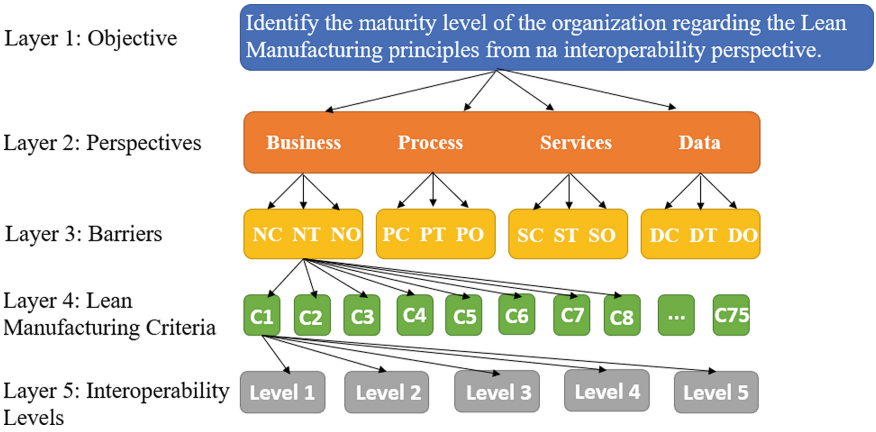

Fig. 2. Structure of the AHP method.

3.1.2 DEMATEL (Decision Making Trial and Evaluation Laboratory)

The DEMATEL (Decision Making Trial and Evaluation Laboratory) multi-criteria method evaluates the criteria interdependence relations in groups of cause and effect, and also evinces critical factors of a complex system through an impact diagram [13]. In the present article, the relevance in the use of this tool is evinced by the diagnostic provided, given that from the impact analysis it is possible to verify the fundamental criteria to achieve the organizational maturity improvement in the LM.

This method is conducted by means of a square assessment matrix, which compares a pair of criteria at a time. In this way, the evaluation of all criteria considered in the AHP method is unfeasible due to the large amount of elements. Then, in order to fill such gap, the Pareto principle was used, which states that 80% of the effects stem from 20% of the causes, that is, 20% of the criteria listed in the AHP can generate 80% of the intended effects.

3.2 Decisional Assessment – PROMETHEE II

The decisional assessment stage is carried out with the use of the PROMETHEE II multi-criteria method (Preference Ranking Organization Method for Enrichment Evaluations). This method compares the performance of the alternatives, one criterion at a time, as a support to decision making. In this method, two groups of elements are added: criteria and alternatives. The criteria were selected and filtered in the diagnostic assessment by using the AHP and DEMATEL methods, while the alternatives were defined with support of the IPM matrix.

As the development of the diagnostic assessment is founded on a hybrid approach of two multi-criteria methods, the balancing of the weights resulting from both methods is necessary in order to add the final value to the PROMETHEE II method. Such balancing was done by bearing in mind that the ranking of the elements resulting from the AHP method is bottom-up, that is, more importance is given to the elements with lower weights. On the other hand, the same elements are ranked with more importance in

the DEMATEL method at their higher positive values, which represent the "Causes" elements of the method.

4 Analysis of Results

4.1 Diagnostic Approach – AHP

After all comparisons made, it is possible to summarize all information inserted in the AHP method and notice that the maturity level of the company with regard to the Lean Manufacturing principles and under the interoperability perspectives is currently Moderate. In addition, the analysis of the interoperability perspectives was carried out (Business, Processes, Services, and Data), indicating that the Business perspective is currently being more fully fulfilled by the company. Such perspective is ranked as Advanced when the company performance is harmonized at all levels and in all areas. The Services perspective, however, has a lower ranking, indicating that the company is possibly not achieving the combined functionality of several services and applications.

4.2 Diagnostic Approach – DEMATEL

Considering the Pareto principle, the selected criteria are presented in Table 1. According to the result from the DEMATEL method, two parameters can be used: RI + CI and RI−CI. The first one provides the relative importance that each criterion has in the system, while the RI−CI identifies "cause" and "effect" factors in the system, quantifying such elements. To proceed with the evaluation in this work, the use of the RI−CI perspective is more relevant, since after the combination with the diagnostic provided by the AHP method, the weights of the criteria will be forwarded to the PROMETHEE II decisional matrix.

Table 1. Detailed result of the DEMATEL method.

Criteria	Description	RI	RI + CI	RI−CI	Classification
PT_5S	Processes-technological-5S	4.51	8.36	0.66	Cause
PT_ED	Processes-technological-waste elimination	3.13	7.66	−1.40	Effect
PT_QUA	Processes-technological-quality	2.75	6.98	−1.48	Effect
PT_TPM	Processes-technological-total productive maintenance	3.93	6.88	0.98	Cause
PT_VSM	Processes-Technological-Value Stream Method	4.40	8.31	0.50	Cause
PT_KZ	Processes-technological-Kaizen	4.80	7.74	1.87	Cause
PT_PA	Processes-technological-standardization	3.97	8.39	−0.45	Effect
PC_KB	Processes-conceptual-Kanban	3.86	7.55	0.18	Cause
PO_5S	Processes-operational-5S	4.65	8.93	0.38	Cause
PO_ED	Processes-operational- waste elimination	4.51	8.07	−1.24	Effect

The RI−CI perspective allows the allocation of the criteria in groups of "causes" and "effects" elements. The "Causes" factors are responsible for impacting on the other criteria of the relational network, while the "Effects" factors are impacted by the former. The criterion with higher potential to impact the others is the "PT_KZ" – "Processes-Technological-Kaizen". The continuous improvement practices, or Kaizen, represent a relevant and influential element to the system, once they comprise continuous improvements to several areas of the company, and thus promote improvements to all processes. With regard to the "Effects" elements, the factor considered as the most influential is the "PT_QUA" – "Processes-Technological-Quality". Quality is considered as one of the results from the continuous improvement (Kaizen), so the impact of these two criteria is tightly related and they are have the highest values of "causes" and "effects".

4.3 Decisional Approach – PROMETHEE II

The decisional assessment in this article provided an approach to the problem under study through the combination of the Lean Manufacturing and Industry 4.0 concepts, so that they can be conjointly applied within the company. The result of this method proved to be extremely relevant as it ranks the alternatives in order to prioritize the technologies that provide the highest maturity increase in relation to the Lean principles.

Among the I4.0 technologies, the top five are ranked as follows: ERP with Analytics; Internet of Things; Product Lifecycle Management (PLM); Predictive Maintenance; and MES/SCADA. The method result showed that the company priority must be the implementation of the ERP with Analytics. The Enterprise Resource Planning (ERP) can be defined as a framework for the structuring, definition, and standardization of businesses processes required to effectively plan and control the organization, and through which the company must be able to use such internal knowledge to pursue competitive advantage [14]. Business Analytics (BA), in its turn, refers to the application of a wide range of data-driven analytical techniques and methods to different business domains [15]. Integrating ERP and BA systems can result in advantages such as: allow real-time recognition control of the cash flow; facilitate the cooperation among departments; reduce the time to create recurring reports; among others [16].

5 Conclusion

Given the increasing need of companies to develop effectively lean and technological processes to sustain organizational competition, the Lean Manufacturing and Industry 4.0 concepts (also known as the Fourth Industrial Revolution) have become models with a great adherence. In this way, and considering the large amount of pillars and tools of these concepts, the implementation of the Lean Manufacturing principles represents a big challenge to companies, while the solutions provided by Industry 4.0 can contribute to the integration perspective.

The final stage of this project leads up to the decisional assessment, which consists in identifying and ranking the Industry 4.0 technologies that must be implemented in order to improve the Lean maturity. With the support of the PROMETHEE II multi-criteria method, the Enterprise Resource Planning (ERP) with Business Analytics (BA)

was indicated as the first technology to be implemented in the company to achieve the maturity improvement of the Lean Manufacturing under the enterprise interoperability perspective. The integration of these concepts can result in advantages to the organization and to the Lean system, since it makes the waste reduction possible, besides providing support to continuous improvement (Kaizen) and to information sharing.

The relevance of this project resides in evaluating how the influences between the Lean Manufacturing and Industry 4.0 are correlated under the quantitative aspect, and considering their organizational barriers so as to propose a ranking of elements to be implemented with priority to improve the organizational maturity level. Additionally, the present project presents an assessment approach that is adaptable to other organizations, allowing the rearrangement to other contexts and to different assessment aspects.

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