Lean Performance Evaluation: Models and Application

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Abstract Lean Manufacturing is based on continuous improvement, aiming at optimizing the production system, eliminating waste and minimizing resources use. In this study, an in-depth analysis regarding the Lean performance evaluation methods present in the literature, as well as already implemented in the industry, is performed, focusing on the gaps of current models and needs for future ones. This paper proposes a method for Lean performance evaluation, following the robust theoretical approaches of existent assessment methods and keeping simplicity of application. The proposed method is divided into two distinct models: The Lean Assessment model and the Lean Maturity model. The Fuzzy logic is used in the models to attenuate the ambiguity and vagueness of the participants' responses. The models' validation was accomplished by comparing the method application in an industrial company with *in loco* Lean assessment.

Keywords Lean manufacturing · Lean performance evaluation · Lean assessment · Lean maturity · Fuzzy logic

1 Introduction

For companies to keep up with the changing market demands, it is necessary to focus on the rapid and efficient production of high quality and low-cost products. Therefore, organizations want to identify ways of reducing costs and time, while

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increasing quality. A good solution for such an objective lies in Lean Manufacturing. This philosophy consists on the continuous reduction of waste (non-added value), producing according to market demand, while optimizing quality [1].

In this context, there is a need to know how to evaluate a company's Lean performance, allowing for identification of Lean training and implementation requirements, as well as for unbalanced knowledge among persons in the company. There were developed Lean evaluation methods by several authors, focusing on measuring the performance and progress of Lean organizations, helping to choose the most appropriate improvement actions and highlighting the areas with potential application [2, 3].

As presented in Sect. 2 of this paper, there are different kinds of Lean evaluation methods. Some of those methods are very simple to implement by companies, usually through a list of questions. Nevertheless, they do not cover all the Lean thinking dimensions, or the output is very limited, just showing direct results from the questions. There are also complex methods with dozens of questions, which analysis requires external consultant elements to do the assessment and the evaluation of results. Based on the limitations of the existent methods, this paper proposes a new Lean evaluation method aiming to be self-applied by the companies, giving comprehensive and meaningful results. The output of the method is visual based, allowing an intuitive identification of the areas which need further improvement. The method was applied in a mould making company, where a two months *inloco* full Lean assessment was also performed. This allowed the assessment of the robustness of the proposed method: the knowledge and implementation gaps regarding Lean Manufacturing identified by the method, corresponded to the ones identified in the *inloco* assessment.

2 Lean Performance Evaluation Methods

Prior to read the following section, the reader should be aware of Lean Manufacturing principles and methods, as well as the origins of Lean Manufacturing: The Toyota Production System. The authors of this paper opted to emphasize the results of the literature review about Lean evaluation methods, recommending for the ones not familiarized with Lean Manufacturing to read [1, 4, 5].

A literature survey was performed by searching Google Scholar, ResearchGate and ScienceDirect databases, using the keywords: Lean Manufacturing, Lean Production, Lean Assessment Review, Lean Maturity Model, Lean Production Audit, and Lean Evaluation.

A common feature identified among the several Lean evaluation models found [2, 3, 6–24] is the use of two definitions: Lean Maturity and Lean Assessment. According to [6–9], Lean Maturity models aim to find the flaws between the company's current practices and the optimal level, with the establishment of improvement strategies and the assessment of competence, capacity and innovation level of organizations through specific criteria while comparing the current state with other

levels or organizations. In addition, those authors claim Lean Maturity models aim to indicate logical paths for the improvement of the organization and to evaluate the impact of Lean principles and tools implementation. The Lean Assessment models, as claimed by [2, 3, 10], are more direct about the practices and the tools applied by the company, and are usually qualitative. In addition, those authors refer the Lean Assessment models are a necessary tool throughout the continuous improvement process, while they help to identify the practices and areas to be developed.

From the analysis of the two central concepts found, it is clear that there is some difficulty in the correspondence of definitions, as some of the characteristics found for both terms represent the same concept. Although, both definitions allow the Lean evaluation and are essential to define the best practices and strategies to be followed.

Despite the unclear differentiation between these two terms, the analyzed publications converge in several characteristics that should be present in Lean evaluation models. An evaluation model must be measurable and aligned with the strategic objectives. It should allow a performance evaluation and the understanding of the current state, assisting in the selection of improvement opportunities, while seeking the balance between the detail of evaluation and its simplicity. Some of the publications refer the self-assessed evaluation process by company elements [8, 12], others proclaim the need for external evaluation by partners or specialists in the area [10, 13].

Regarding the model's structure, there are several alternatives. The use of questions is the most common structure in the analyzed models [14, 16]. Others structures are based in statements or indicators [17–19]. Some of the methods assess directly the company about Lean methods and tools, while others ask questions without mentioning the Lean-related themes [20, 21]. Concerning the number of analysis fields, there are models using uniform number of fields per category, others have a non-uniform field number [15, 18]. Some of the models propose a long list of items to analyze [17] with 162 fields to fill, others present a very short list [19] with only with 8 fields. Of course, some of them are in between, having a balanced number of topics [15, 22] ranging between 20 and 50 fields to fill.

Among the existing models some use qualitative approach other use quantitative approach. There are also many models which use both types of analysis, especially in the form of fuzzy logic [3, 10, 12, 17]. The Likert Scale is the most commonly used evaluation scale [18].

Some of the models aim to cover all the Lean related areas [12, 20], other proposed a specific focus evaluation [16]. Finally, the results are presented as a single value, as a list of best-performing categories or as a visual scheme. The different models' features analyzed are listed in Table 1.

As a conclusion of survey of Lean evaluation models published in literature, there is no typical structure for a Lean evaluation method, neither a clear definition of the difference between Lean Maturity and Lean Assessment models. This aspect is also referred by other authors [11, 14]. The complexity of some models is high, hence the authors propose the existence of an external assistant for its implementation [14]. The use of explicit Lean-related terms differs among models, which may have a negative influence on the results, in case the company elements are not aware of those terms

Table 1 Differentiating features of lean performance evaluation models. Based on [2, 3, 6–24]

Evaluation process	Self-assessment		External assessment
Participants	Single		Multiple
Structure	Questions	Statements	Indicators
Approach	Direct		Indriect
Number of fields	Uniform		Non-uniform
Extension	Extended	Balanced	Short
Analysis	Qualitative	Quantitative	Qualitative and quantitative
Evaluation scale	Likert scale		Other scale
Focus	Integral		Specific
Result	Single value	List	Visual scheme

[20]. Some models do not cover all Lean areas, therefore they do not accurately represent the overall level of Lean performance, as mentioned by Zanjirchi et al. [15]. Other critical aspects were found through this analysis and were pointed by some of the models' authors: there are quite extensive models, although they are complete [11]; there are unbalanced models in terms of fields per category [12, 24]; some models are not cleared about the actions to be taken after the analysis [11].

Hence, there is a need to develop a Lean self-evaluation model that allows a clear, simple, direct and comprehensive analysis of the results, covering all the Lean essential areas.

3 The Proposed Lean Evaluation Method

The proposed evaluation aims to assess the company's regarding Lean Manufacturing knowledge and implementation, and to be useful by selecting the action and training action required towards performance improvement. It takes into account that there are companies with Lean knowledge, although they have difficulties implementing the best practices; companies which implement good practices, although they have a low formal knowledge concerning the Lean principles and tools; and companies whose lack of knowledge in Lean hinders the implementation of continuous improvement actions. For the proposed method's design several requirements were taken into account, having in mind the published work and gaps identified in Sect. 2. In summary, the method must (i) be simple enough to allow self-assessment by the company, therefore the output should easy to interpret; (ii) include all the hierarchy levels in the assessment; (iii) have a quantitative evaluation (not exclusively); (iv) use terms which are easily understood by the participants so the filling is consistent and the final result realistic; (v) enable a comprehensive assessment, encompassing key fundamentals and Lean methods, but have no more than 50 questions; (vi) identify Lean areas with potential opportunities for improvement.

In order to have no influence from the ambiguity on the participants' responses and considerations, together with a numerical result, the simultaneity of the quantitative and qualitative analysis, a fuzzy logic data treatment is used—this data treatment in not visible to the user. Regarding the evaluation scale, a seven-level Likert Scale with equidistant intervals was selected for the method. One of the challenges regarding the method's design was to cover both dimensions of evaluation: the level of knowledge and the level of implementation. To deal with these two dimensions, the method is composed by two distinct parts, with different objectives: The Lean Assessment model and the Lean Maturity model. The two models can be used separately, since they have different objectives. However, when used in the same company, it makes the analysis more complete.

The Lean Assessment model aims to measure each employee's perception of Lean methods implementation in the company, as well as the personal knowledge of these methods and Lean fundamentals. This model does not aim to assess the implementation level, but only the individual perception about the level of implementation. In addition, it intends to assess the individual perception about Lean principles and tools. This model's output allows the comparison of perceptions among different elements of the company. The Lean implementation's level is not the main subject, but the focus on the individuals' willing to acquire more knowledge about Lean and/or to ask for a higher implementation level, despite the "real" one. The Lean fundamentals, vocabulary, methods, and problem-solving actions are the ones assessed in this model (Table 2). Each individual must classify each item according to a seven-level Likert Scale (Table 2). The inputs (answers) are computed using the fuzzy logic approach, in order to attenuate the ambiguity and imprecision which is characteristic from numerical values or exact linguistic expressions [12]. In this paper there is not enough space to explain the fuzzy logic parameters and equations, however they are explained in [25]. Finally, a visual representation is outputted where the results of different elements from different areas are plotted. In Fig. 1 the output from the model's application in a mold making company is presented. There are various conclusions after this model's application. However, the most obvious one is the distinguished perception of Lean implementation among the different elements. Matching this analysis *vis-à-vis*, the assumed knowledge about each topic (not presented), allows the identification of which actions should be taken regarding improvement and training practices.

The Lean Maturity model seeks to assess the importance associated to the practice of each Lean's fundament or method, along with the level of implementation. This model's questions approach the type of procedures and practices used in the company, with no direct question using Lean terms. Naturally, all the questions are linked with a Lean fundament or method, aiming to allow a comprehensive assessment. This model complements the Lean Assessment one, as it was designed to: (i) have an accessible vocabulary which facilitates its filling; (ii) evaluate all the organization's essential areas as well as the Lean related practices; (iii) permit to identify differences between distinct hierarchy levels; (iv) obtain a result that clarifies the areas in which to act.

Table 2 Lean concepts in the Lean Assessment model (a) and Knowledge and Implementation weights scale for Lean Assessment model (b)

(a)

Fundamentals	Just In Time (JIT)
	Jidoka
	Heijunka
	Standardized Work
	Kaizen
Vocabulary	Muda, Muri e Mura
	Work In Process (WIP)
	Lead Time
	Takt Time
	Overall Equipment Effectiveness (OEE)
Methods	5S
	Single Minute Exchange of Die (SMED)
	Total Productive Maintenance (TPM)
	Poka-Yoke
	Kanban
Problem-solving	PDCA (Plan, Do, Check, Act)
	Go to Gemba
	Kaizen Events
	Value Stream Mapping (VSM)

(b)

Knowledge weight		Implementation weight	
Very low	1	Very low	1
Low	2	Low	2
Relatively low	3	Relatively low	3
Medium	4	Medium	4
Relatively high	5	Relatively high	5
High	6	High	6
Very high	7	Very high	7

The Lean Maturity model is divided into importance weight (scale similar to Lean Assessment model) and implementation weight (seven-level scale based on frequency—never to always). The importance weight allows employees to express their point of view regarding the importance of each Lean foundation and method. The implementation weight expresses the company's performance in the described good practices. Thus, it is possible to understand the most relevant fundamentals and tools according to the company elements, as well as which wastes type and principles

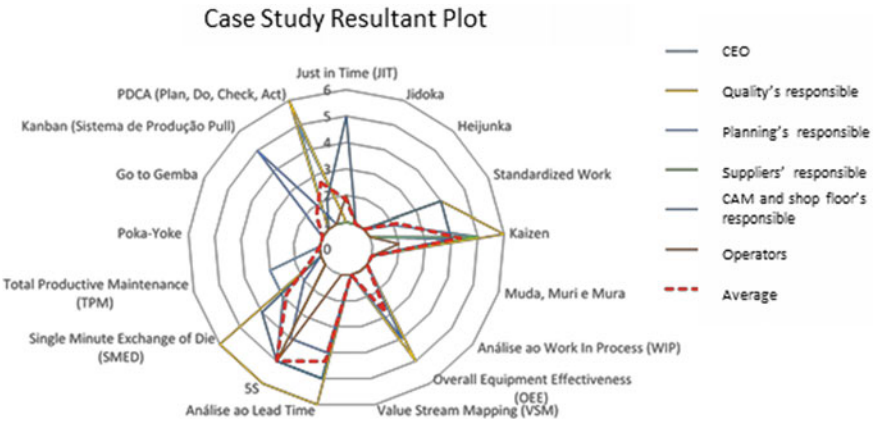

Fig. 1 Final output of Lean Assessment model for the case study company regarding the implementation level

are covered by these fundamentals and tools implementation. Fuzzy logic was also used to compute this model's inputs.

The model's questions were based on Lean principles, following a coherent logic and assigning a fair weight to each of the fundamentals. The TPS House [6, 8] was used as one of the foundations to assure comprehensiveness, since it is an organized way of presenting the fundamentals. In addition, the types of waste (*Muda*, *Mura* and *Muri*) were used for the questions' categorization, to ensure that all of them were addressed in the same way. The questions' organization were based on the traditional 5Ps model for Lean Manufacturing. The full questionnaire is presented in Table 3, where is possible to check the balance of all covered areas. Finally, the results are showed using the TPS House aiming to allow an easy and intuitive interpretation of the results. In Fig. 2 the application of the Maturity model to the case study company is presented. The result is showed using colors, complementing the quantitative value obtained from fuzzy logic, allowing the observation of how far is the performance to change for the next level (not represented in this paper). In this case, the CEO filled out the complete questionnaire and the heads of each department fill out only the questions related to their area. The obtained results matched the *in-loco* analysis where it was found that most of the Lean areas were considered with a high importance (good), although there were flaws in the implementation of people's empowerment strategies. Besides, collaborators focus on internal planning and technical/quality aspects, but they do not give enough attention to customer specific needs and to the right strategies for keeping the design and production activities stable during the weeks.

Table 3 Lean Maturity model questions and categories

5P	Question	3M	TPS House
Product	Do you evaluate the quality of the final product?	Defects/rework	Customer
	Do you use mechanisms which avoid the error?	Defects/rework	Jidoka
	Do you use quick response strategies to nonconformities?	Talent	Jidoka
	Do you use standardization strategies for the exchange and availability of information?	MURA	Standardization
	Do you ensure employees' alignment with the strategic objectives of the company?	–	Stability
	Are there mechanisms to disseminate the company's mission?	–	Stability
	Do you use systems which prevent error propagation (defects)?	Defects/rework	Jidoka
Plant	Are the safety aspects reviewed?	–	Customer
	Do you apply day-to-day visual management?	MURI	Involvement
	Do you promote the use of standardized procedures for the management of operational spaces?	Motion	Standardization
	Do you have internal transportation routes established?	Transportation	Standardization
	Do you check the equipment's operational performance?	Waiting	Jidoka
	Are the workstation's organization and tidiness audited?	Motion	Stability
	Do you evaluate the impact of component and product transportation?	Transportation	JIT
Processes	Are production costs evaluated?	MUDA	Customer
	Do you measure setup times?	Waiting	JIT
	Do you use formal problem -solving approaches?	MUDA	Jidoka
	Do you control process variability?	MURA	Jidoka
	Do you develop internal projects for continuous improvement?	MUDA	Involvement
	Do you apply Standardized Work formally?	MURA	Standardization
	Do you use production levelling methods (*Heijunka*, "one-piece-flow")?	Overproduction	Standardization
Planning	Do you evaluate operations' Lead Time?	Waiting	Customer
	Do you confirm Pull production logics' application for all products?	Overproduction	JIT

(continued)

Table 3 (continued)

5P	Question	3M	TPS House
	Do you analyse the product flow?	Inventory	JIT
	Do you confirm the Takt time accomplishment?	Waiting	JIT
	Do you analyse the WIP (Work in Progress)?	Inventory	JIT
	Do you check the existence of unnecessary operations/processes from the customer's perspective?	Over processing	Customer
	Do you check if there is equipment overload, and there is another without load?	MURI	Stability
People	Are employees' levels of motivation measured?	Talent	Customer
	Do you develop strategies for employees' involvement and decision autonomy?	Talent	Involvement
	Do you support teamwork in projects?	Talent	Involvement
	Do you promote employee's flexibility in terms of skills?	MURI	Involvement
	Do you use strategies which promote "doing well at first"?	Defects/rework	Stability
	Do you promote cross-audits to identify redundancies?	Over processing	Involvement
	Do you verify the levels of exhaustion and pressure on employees?	MURI	Stability

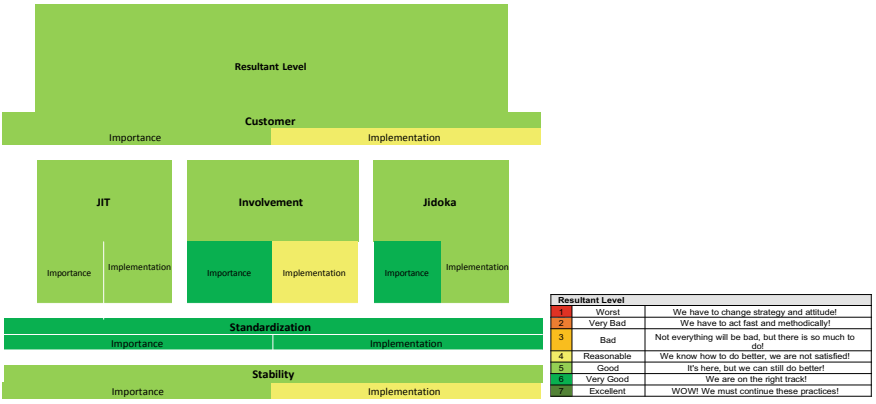

Fig. 2 Final output of Lean Maturity model for the case study company

4 Conclusions

This work aims to propose a new Lean evaluation method, based on the identified gaps on the existing Lean performance evaluation methods published. Comparing with the reported models, the one proposed guarantees a consistent and measurable evaluation, a balance between the model extension and the evaluation detail, and an easy filling. The several aspects identified during the literature review were covered by the application of the two different models. They address all the essential Lean fundamentals and tools allowing the company a complete analysis. Regarding the models' results, both helped choosing the most appropriate improvement actions to be applied in the company, clearly exposing the most needed areas. The developed Lean Assessment model's goal is to measure each employee's perception of personal knowledge and the company's implementation of Lean fundamentals and tools. Compared to the existing ones, this model focus on people and compares perceptions and knowledge among the various participants. It confirms to be a model of rapid application and results. The developed Lean Maturity model's purpose is to assess the importance assigned to each good practice, together with the frequency of implementation in the organization.

The method was applied in a company, as the *in-loco* assessment confirm the method results.

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References

1. Womack JP, Jones DT, Roos D (1992) The machine that changed the world. Bus Horiz
2. Al Amin M (2013) A systematic approach for selecting lean strategies and assessing leanness in manufacturing organizations. Management
3. Susilawati A, Tan J, Bell D, Sarwar M (2015) Fuzzy logic based method to measure degree of lean activity in manufacturing industry. J Manuf Syst
4. Womack JP, Jones DT (1997) Lean thinking−Banish waste and create wealth in your corporation. J Oper Res Soc
5. Yazdani B (2003) Toyota production system: an integrated approach to Just-In-Time. Comput Integr Manuf Syst
6. Nesensohn C, Bryde D, Ochieng E, Fearon D, Hackett V (2014) Assessing lean construction maturity. In: 22nd annual conference of the international group for lean construction: understanding and improving project based production, IGLC 2014

7. Becker J, Niehaves B, Pöppelbuß J, Simons A (2010) Maturity models in IS research. In 18th European conference on information systems, ECIS 2010
8. Urban W (2015) The lean management maturity self-assessment tool based on organizational culture diagnosis. Procedia Soc Behav Sci
9. Cronemyr P, Danielsson M (2013) Process management 1-2-3—a maturity model and diagnostics tool. Total Qual Manag Bus Excell
10. Vinodh S, Balaji SR (2011) Fuzzy logic based leanness assessment and its decision support system. Int J Prod Res
11. Srinivasaraghavan J, Allada V (2006) Application of Mahalanobis distance as a lean assessment metric. Int J Adv Manuf Technol
12. Vinodh S, Vimal KEK (2012) Thirty criteria based leanness assessment using Fuzzy logic approach. Int J Adv Manuf Technol
13. Hosseini Nasab H, Aliheidari Bioki T, Khademi Zare H (2012) Finding a probabilistic approach to analyze lean manufacturing. J Clean Prod
14. Da Wan H, Frank Chen F (2008) A leanness measure of manufacturing systems for quantifying impacts of lean initiatives. Int J Prod Res
15. Zanjirchi SM, Tooranlo HS, Nejad LZ (2010) Measuring organizational leanness using Fuzzy approach. In: Proceedings of the 2010 international conference on industrial engineering and operations management
16. Gonçalves MT, Salonitis K (2017) Lean assessment tool for workstation design of assembly lines. Procedia CIRP
17. Bayou ME, de Korvin A (2008) Measuring the leanness of manufacturing systems-a case study of Ford Motor Company and General Motors. J Eng Technol Manag JET-M
18. Sânchez AM, Pérez MP (2001) Lean indicators and manufacturing strategies. Int J Oper Prod Manag
19. Behrouzi F, Wong KY (2011) Lean performance evaluation of manufacturing systems: a dynamic and innovative approach. Procedia Comput Sci
20. Doolen TL, Hacker ME (2005) A review of lean assessment in organizations: an exploratory study of lean practices by electronics manufacturers. J Manuf Syst
21. Vinodh S, Chintha SK (2011) Leanness assessment using multi-grade fuzzy approach. Int J Prod Res
22. Chan FTS, Qi HJ (2003) An innovative performance measurement method for supply chain management. Supply Chain Manag
23. Pakdil F, Leonard KM (2014) Criteria for a lean organisation: development of a lean assessment tool. Int J Prod Res
24. Soriano-Meier H, Forrester PL (2002) A model for evaluating the degree of leanness of manufacturing firms. Integr Manuf Syst
25. Barros M (2019) Lean performance evaluation: models and application. Instituto Superior Técnico, Universidade de Lisboa, Portugal