System of indicators with a fuzzy-base to evaluate the lean level

MsC. Lissette Concepción Maure
Industrial Engineering Department, Universidad Central "Marta Abreu" de Las Villas, Cuba
lissette@uclv.cu

DrC. René Abreu Ledón
Industrial Engineering Department, Universidad Central "Marta Abreu" de Las Villas, Cuba

Prof. Dr.-Ing. Dr. h.c. Norge Isaias Coello Machado
Mechanical Engineering Department, Universidad Central "Marta Abreu" de Las Villas, Cuba

Prof. h. c. Dr.-Ing. Dr. h. c. (UCLV) Elke Glistau
Institute of Logistics and Material Handling Systems, Otto von Guericke University, Germany

DOI: http://dx.doi.org/10.25673/85942

Abstract

Companies need to systematically and visibly manage the degree of leanness of their processes and evaluate the implementation of new smart manufacturing projects as part of the new industrial revolution. For this, it is necessary to identify indicators that support the decision-making process.This article proposes a measurement system with a tree-like structure of key performance indicators (KPIs) and key result indicators (KGIs). KPIs determine how well the process is performing to achieve results, indicating whether or not it will be feasible to achieve a goal. KGIs define measures to report whether a process met business objectives. Indicators and their supporting measurement elements are identified and classified in a multi-level hierarchy designed to provide answers at the strategic, tactical, and operational levels. In this way is possible to design a hierarchical framework that allow to indicate the casual relationship between different levels of KPI. The tool uses fuzzy logic with two objectives: 1) to allow the treatment of uncertainty and subjectivity associated with the casual relationship between different levels of KPI and supporting elements and the relationship between the indicators 2) for vague and ambiguous data as input parameters to the model from different domains and scales.

1. Introduction

Lean manufacturing (LM) is an integrated socio–technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer and internal variability. LM encompasses individual management practices that can work synergistically to create an optimized system.

However, companies that have been applying lean tools and methodologies show shortcomings in the evaluation of their improved performance. The causes cited for this gap are largely due to a lack of understanding of the concept of lean performance and appropriate models to monitor, evaluate and compare the evolution of "lean level". In a lean implementation process it is necessary to use indicators to monitor progress and support the decision-making process. A structured framework of performance indicators is crucial in measuring the distance between the current and the desired operations, identifying the track progress towards closing the productivity gaps [1, 3].

Currently most organizations use qualitative evaluation methods based on questionnaires or a group of metrics used simultaneously to determine the level of application/implementation of the methodologies and lean tools. The challenge of using performance indicators and metrics concerned with the assessment of the lean level of an organization, it is the ability to define a set of indicators including all dimensions of the lean approach. Furthermore, the synthesis of a set of indicators in a single lean metric is also in itself a challenge due to the different measurement units.

Fuzzy logic modelling offers a simplistic yet comprehensive approach to lean performance evaluation, while allowing the use of qualitative and quantitative indicators simultaneously.

In this context, this paper presents a model based on fuzzy logic that aims to determine the lean level of an organization, which could be seen as a modelling and decision-making tool for complex systems. The tool uses fuzzy logic allow the treatment of uncertainty and subjectivity associated with the casual relationship between different levels of KPI and supporting elements and the relationship between the indicators.

The paper is structured as follows: on section 2 is discussed the need to measure the lean level of an organization, main perspectives to assessing the level of leanness that has been suggested in literature, and main advantages that can be generated by the use of fuzzy logic in the evaluation of the lean level. Section 3 presents a detailed description of the lean assessment approach proposed.

2. Research background and Fuzzy Logic

Nowadays, when the subject of productivity and business success is addressed, there are several relevant issues that are the subject of research, for example: Why are not all organizations successful? Why the success formulas do not apply equally in all situations? What does it mean to be lean? How lean are the processes of our organization? How can my organization quantify the fats identified? And what is the most appropriate lean evaluation model in order to monitor strategies for increasing productivity and continuous improvement? [2,13].

We can find in the literature several definitions for the term lean level of an organization. For example, the lean level as the performance level of the stream value compared to perfection, a measure of the implementation of lean practices, or absence of fat that it means less use of the inputs to fulfil the objectives of the organization and an improvement in the outputs. Thus, one of the major challenges facing this area, it is related with the development of models to assess and validate the effectiveness and efficiency of lean thinking implementation in organizations [11].

According to some authors, lean assessment methods can be categorized into four groups: Value Stream Mapping (VSM), Qualitative Assessment Tools, Performance Indicators and Benchmarking [4]. Although there are several different methods of measuring the various perspectives of lean production, in literature there is no holistic assessment approach to determine the level of implementation of lean thinking in organizations [11].

2.1. Research Background

The reference [5] proposes the performance pyramid (see figure. 1) with the purpose to link the hierarchical view of business performance measurement with the business process review. On the top of the pyramid there is a corporate vision that depends on market and financial goals (e.g. market share, return on investment, etc.). At an intermediate level, objectives deal with achieving and maintaining high productivity and quality, with fast response, sufficient flexibility, and short lead times. At the bottom level there are the operations mainly characterized by non-financial indicators (e.g. cycle time, material losses, mean time to failure, etc.). The pyramid points to a range of target related to both external effectiveness and internal efficiency [1].

These objectives can be achieved through measures at various levels in the hierarchy as shown in the pyramid at the right side of figure 1. The measures interact with each other both horizontally at each level, and vertically across the levels in the pyramid. [12]. Obviously, the pyramid is a tool that requires to be adapted to different industrial contexts, and it represents a very interesting approach for implementing a Performance Measurement Systems (PMS) in a competitive company. The design of the whole framework, the identification of the proper Key Performance Indicators (KPIs) and the implementation of the monitoring system, represents currently the real challenge for most manufacturing plants.

The PMSs are considered essential in manufacturing processes, since they allow monitoring and controlling the factory facilities in order to enhancing the productivity and improving the manufacturing system performance. A PMS consists of a set of metrics that are able to quantify the efficiency and effectiveness of manufacturing operations according to a top-down perspective, that depends from both internal and external factors. In manufacturing systems, once a KPI set is defined in a PMS, every parameter reflects one facet of the system performance [1].

According to ISO 22400, KPIs are defined as quantifiable and strategic measurements that reflect the critical success factors of an organization. Key performance indicators are very important for understanding and improving production efficiency. The values achieved by the KPIs are very helpful in the decision-making process, enabling the identification of problems and the undertaking of corrective or improvement actions. Proper use of information from the KPI measurement should contribute to more effective management of the organization's resources [9].

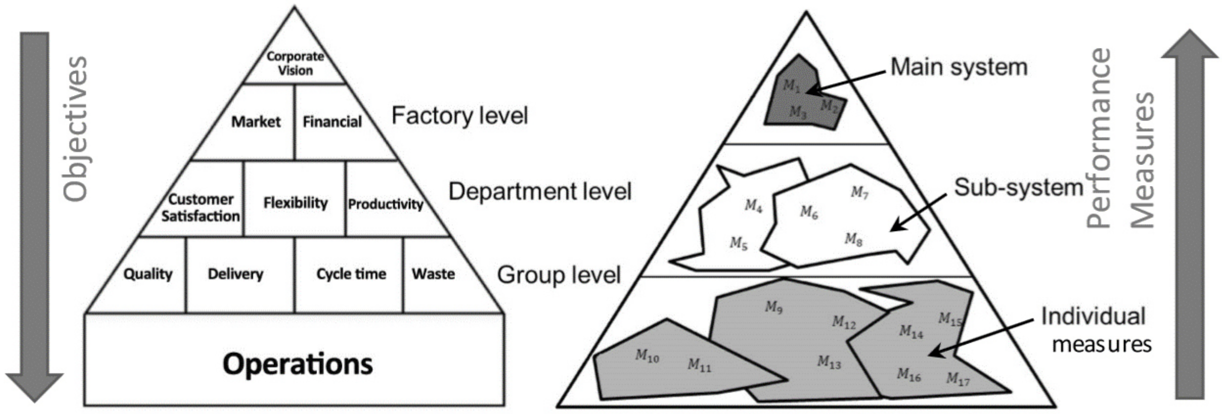

Figure 1: The performance pyramids [1]

2.2. Fuzzy Logic

From the point of view of socioeconomic phenomena, it is necessary to have models that more accurately capture reality, since it involves imprecision, lack of definition, lack of borders, subjectivity, undefined classifications, etc., that is concepts and variables are manipulated that do not fit with classical logic and, however, for their analysis it is necessary to use mathematics.

Precisely, in the search for models that take these realities into account, fuzzy logic emerges as a mathematical model that allows the use of concepts related to reality following behavior patterns similar to human thought [7].

A fuzzy logic system converts input variables (quantitative and qualitative) into linguistic variables through membership functions or fuzzy sets, which are evaluated using a set of if-then fuzzy rules. Then the system outputs are converted into crisp values (crisp) through a process of concretion (defuzzification), which allow providing information for decision making. A fuzzy logic system uses any type of information and processes it in a similar way to human thought; For this reason, fuzzy logic systems are suitable for dealing with qualitative, inaccurate and uncertain information, which also allow dealing with complex processes, which makes it an interesting alternative for modeling decision-making problems [7].

Fuzzy logic is related to and based on the theory of fuzzy sets, according to which the degree of membership of an element in a set is determined by a membership function that can take all the real values included in the interval (0, 1). In this way, while in the rigid framework of formal logic the utility of a company, for example, is low and gives it a value of zero, or is high and gives it a value of one, for fuzzy logic it is possible also all the intermediate conditions of utility such as “very low”, “slightly low”, “medium”, “relatively high”, etc.

The essential steps for the design of a fuzzy system are [6]:

Identification of the type of problem and the type of fuzzy system that best fits the data.

1. Definition of input and output variables, their fuzzy values and their membership functions (fuzzification or parameterization of input and output variables).
2. Definition of the knowledge base or fuzzy rules.
3. Obtaining system outputs through the information of the input variables using the fuzzy inference system, which uses composition operators.
4. Transfer of the fuzzy output of the system to a clear or specific value by means of a defuzzification system.
5. Adjustment of the system validating the results.

3. Results and Discussion

The methodology to implement a fuzzy aggregation method is compound by nine steps; each one is described as follows:

1. Choose an indicator’s set for each perspective: the reference [8] perform a comprehensive review of the literature, presenting an overview of current Lean assessment tools, methods, and techniques available in the literature, demonstrating the dimensions used in each. This analysis is taken as a basis to propose an evaluation tool in this section.

2. Build a global indicator based on the statistical analysis: the main goal in this step is to know how we can group the indicators ensures the maximum correlation among the items in the component and minimum correlation among the components.

3. Indicator fuzzification: Every time we want to build new indicators based on aggregation methods is important to normalize the indicators. A sigmoidal membership function is proposed as an aggregation method. The parameters of these functions are determined by setting two values. The first is the value at which it is considered that the statement in the predicate is true (gamma). The second is the value for which the data makes almost unacceptable the corresponding statement (beta) [10]. The sigmoidal membership function is calculated as follows:

$$S\,(x, \alpha, \gamma)_k = \frac{1}{1+e^{-\alpha(X_k-\gamma)}} \quad (1)$$

$$\alpha = \frac{\ln(0.9)-\ln(0.1)}{\gamma-\beta} \quad (2)$$

Where:
S: Value of truth of the criterion of measurement of indicator "k"
Alfa (α): Sigmoidal function parameter
X: Calculated value of the indicator "k" according to the company
Gamma (γ): Value acceptable. It would be equal to the value at which the indicator is considered acceptable.
Beta (β): Value almost unacceptable: It would be equal to the preimage of a symmetric sigmoidal function for the optimal value defined for the indicator.
The evaluation of the qualitative indicators is carried out through a table work of the group of experts. These will give a truth value between 0 and 1 where the values closer to 1 are considered as higher truth values that indicate the degree of compliance with the approach of the descriptor in the area. To do this, we will work with the scale shown in Table 1. Given that this scale covers the widest spectrum of verbal predicates possible in the analysis of the experts (very high, high, medium, low, very low and terrible), it also considers that truth values less than 0.5 indicate the falsity of the predicate, so the analysed descriptor is assumed to be lousy in compliance with the premises of fuzzy logic [10].

Table 1: Scale to determine the behaviour of qualitative indicators

Ratio	Range
Very high	1-0.9
High	0.9-0.8
Medium	0.8-0.7
Low	0.7-0.6
Very low	0.6-0.5
Critical	0-0.5

4. Estimation of the weighting coefficients: the weighting coefficients represent the relationships of relative importance in the multi-criteria aggregation process. For the evaluation of these coefficients, the Analytical Network Process (ANP) is used [14]. The ANP allows to generate a network, considering all the existing relationships between the levels (perspectives) and between the alternatives (indicators) without having to assume axioms of independence. This uses a super matrix approach to calculate the weighting factors and check the consistency of the exercise through the vectors and eigenvalues. As a result, a set of weighting factors is obtained (by perspective, by descriptor and equivalent) that are less sensitive to judgment errors and whose consistency can be determined quantitatively. The scale to define the weights will be a continuous number between [0, 1].
5. Aggregation fuzzy methods: a global indicator is build considering the weight for each simple indicator and its value of truth. Under the principles stated above and using compensatory fuzzy logic to compensate the global indicator, would be defined as follows:

$$GI = \forall_{j=1}^{j=n} \left[W_j \rightarrow V_j\right] \in [0,1] \quad (3)$$

Where:
Gi: Value of truth of the global indicator "i"
W_j: Weight of the "j" simple indicator
V_j: Value of truth of the simple indicator "j".
The result set from the expression 3 will be a continuo's number among [0, 1] where one is the optimal result and zero the worst result [10].
While quantitative assessment tends to result in an acceptable performance level, qualitative assessment reflecting stakeholders' perceptions or the context of the firm may create different assessment perspectives. Therefore, the lean index was built using both quantitative and qualitative measures, to give an overall view of the organization's leanness efforts. The measures utilize a ratio-based approach, using fuzzy logic, integrating five main performance dimensions (Quality, Customer, Process, Human resources, Cost). The section integrates a perceptional approach with 61 quantitative and qualitative items.

Quality

Q1. Defect rate
Q2. Rework rate
Q3. Scrap rate
Q4. Failure rate at final inspection (First time through)
Q5. Inspection carried out by autonomous defect control (poka-yoke devices)
Q6. Employees identify defective parts and stop the line.
Q7. Processes are controlled through measuring inside the process.
Q8. Process-focused management is employed in throughout the firm.

Customer

C1. Customer satisfaction index
C2. Market share (market share by product group)
C3. The customer complaint rate
C4. Customer retention rate
C5. Total number of products returned by the customer/total sales
C6. Our customers are directly involved in current and future product offerings.
C7. We have frequent follow-up with our customers for quality/service feedback

Process

<u>Production Process</u>

P. PP 1. Overall Equipment Effectiveness (OEE)
P. PP 2. Size of the adjustment and repair area/total area
P. PP 3. Capacity utilization rate (idle capacity/total capacity)
P. PP 4. Space productivity
P. PP 5. Kanban, squares, or containers of signals are used for production control.
P. PP 6. Equipment is grouped to produce a continuous flow of products
P. PP 7. SPC techniques to reduce process variance.
P. PP 8. TPM is applied throughout the firm.
P. PP 9. Value stream mapping is employed in throughout the firm.
P. PP 10. Non-manufacturing operations are standardized.

<u>Time Effectiveness</u>

P. TE 1. Cycle time
P. TE 2. Takt time
P. TE 3. Total down time/total machine time
P. TE 4. Total time spent on unplanned or emergency repairs/total maintenance time

<u>Inventory</u>

P. I 1. Stock turnover rate
P. I 2. Total inventory/total sales
P. I 3. Raw material inventory/total inventory
P. I 4. Total work in progress/total sales

<u>Delivery</u>

P. D 1. Number of times that parts are transported/total sales
P. D 2. Average total of days from orders received to delivery
P. D 3. Order processing time/total orders
P. D 4. Total of orders delivered late per year/total of deliveries per year
P. D 5. Production is pulled by the shipment of finished goods.
P. D 6. Production at the stations is pulled by the current demand of the next station.
P. D 7. To establish long-term relationship with our suppliers.
P. D 8. To include our key suppliers in our planning and goal-setting activities.
P. D 9. Suppliers are directly involved in the new product development process.
P. D 10. Key suppliers deliver to plant on JIT basis.
P. D 11. We and our trading partners exchange information that helps establishment of business planning.

Human Resources

HR1. Labour turnover rate
HR2. Total indirect employees/total direct employees
HR3. Total of employees involved in lean practices/total employees
HR4. Total of problem-solving teams/total employees
HR5. Sales per employee
HR6. Employee drive suggestion programs.
HR7. Continuous improvement and compensation link is evident.
HR8. Operators and supervisors are cross functionally trained and flexible to rotate into different jobs.
HR9. Leaders are responsible for how the value-added work gets done

Cost

Co1. Annual transportation costs/total sales
Co2. Inventory costs/total sales
Co3. Total warranty costs/total sales
Co4. Total cost of poor quality/total costs
Co5. Total cost/total sales
Co6. Average cost per unit
Co7. Total prevention costs/total costs
Co8. Total prevention costs/total sales

The lean index is modelled in Fuzzy Tree Studio Software. Figure 2 shows the five defined perspectives and as an example in figure 3 it is indicated how the simple predicates are established for each of the perspectives. These predicates correspond to fuzzy variables that have been normalized (quantitative) or linguistic labels (qualitative).

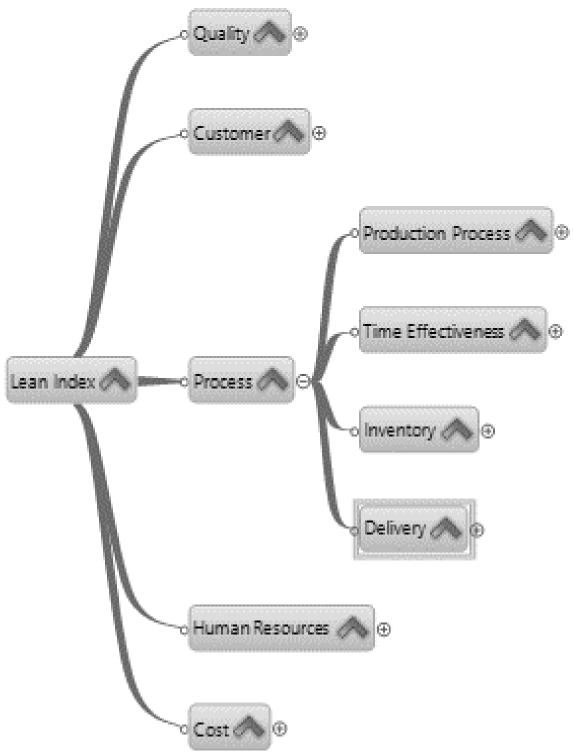

Figure 2: Fuzzy tree to calculate the lean index

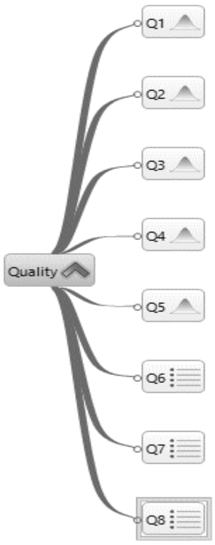

Figure 3: Fuzzy tree to calculate a perspective

Once designed the fuzzy tree in the system must be associate the data set. To analyze the lean index must be analyzed individually the behavior of each predicates and the overral indicator . The scale was defined, considering the same values of truth of Table 1.

4. Conclusion

Multiple assessment tools have been designed to measure different and often individual aspects of lean implementation. While some existing studies measure leanness level through perceptual evaluations, other studies utilize a quantitative assessment approach. Using only one qualitative or quantitative approach in lean assessment efforts may create a bias both in practice and theory. While quantitative assessment leads the organizations to an acceptable leanness level, stakeholders' perceptions about leanness level may result in an opposite result. To decrease this possibility, organizations should utilize both perceptional and measurement approaches simultaneously to assess their lean implementation efforts. Therefore, this index employs an evaluation approach that includes both quantitative and qualitative bases, constructed on fuzzy logic.

The lean level indicator provides a diagnosis that allows to adequately guide the improvement approach to be followed in a company. The evaluation considers five fundamental components: quality, client, process, human resource, cost integrating 61 items (quantitative and qualitative). This indicator was developed under the principles of compensatory fuzzy logic, based on the advantages of using fuzzy predicates and their representation through fuzzy trees. The use of Fuzzy Tree Studio allows the evaluation to be relatively easy to carry out, thus being a feasible tool to apply.

5. References

[1] Ante, G.; Facchini, F.; Mossa, G.; Digiesi, S. (2018): Developing a key performance indicators tree for lean and smart production systems. In Proceedings IFAC. Conference Peper archive, pp. 13-18.

[2] Bayou.,M.; Korvin, A.(2008): Measuring the leanness of manufacturing systems- a case study of Ford Motor Company and General Motors. Journal Engineering Technol Manage, 25:287-304.

[3] Behrouzi, F.; Wong, K. (2011): Lean Performance Evaluation of Manufacturing Systems: A Dynamic and Innovative Approach. Procedia Computer Science 3: 388–395.

[4] Boenzi, F.; Digiesi, S.; Facchini, F. (2015): Greening activities in warehouses: Amodel for identifying sustainable strategies in material handling. In Proceedings of the International DAAAM Symposium, pp. 980-988.

[5] Cross, K.; Lynch, R. (1992): For good measure. CMA Magazine, 66:20-24.

[6] Dubois, D.; Prade, H. (1985): Review of fuzzy set aggregation connectives. Information sciences.

[7] Facchinetti, G. (2001): Fuzzy expert systems: Economic and financial applications. Advanced computer system, 8:3-26.

[8] Fatma, P.; Moustafa, K. (2014): Criteria for a lean organisation: development of a lean assessment tool. International Journal of Production Research 52: 4587-4607.

[9] ISO 22400-1:2014 (2014): Automation systems and integration - Key performance indicators (KPIs) for manufacturing operations management - Part 1: Overview, concepts and terminology.

[10] Marin, P.; Pérez, P.; Gómez, J. (2013): Compensatory Fuzzy Logic Uses in Business Indicators Design. Eureka-. International Workshop Proceedings, pp. 303-309.

[11] Ray, D.; Zuo, X.; Wiedenbeck, J. (2006): The lean index: operational lean metrics for the wood products industry. Wood Fiber Sci, 38:238-255.

[12] Tangen, T. (2004): Performance measurement: from philosophy to practice. International Journal of Productivity and Performance Management, 53: 726-737.

[13] Vinodh, S.; Balaji R. (2011): Fuzzy logic based leanness assessment and its decision support system. International Journal Production Research, 49:4027-4041.

[14] Z Ayağ, R; Özdemİr, R. (2007) An intelligent approach to ERP software selection through fuzzy ANP. International Journal of Production Research, 45:2169-2194.