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Fuzzy Model To Assess The Level Of Lean Manufacturing In A Commercial Air Conditioning Manufacturer

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Abstract:
***Background**: Proper management of factory floor resources have fundamental importance for the financial health and survival of the companies. Organizations that work with high levels of waste lose competitiveness due to constantly directing their efforts and investments into corrections instead of new technologies. Waste must be studied and eliminated or mitigated to guarantee the generation of profit. For this purpose, the company chosen as the object of application of the research started using the tools of the Lean manufacturing methodology. This work aims to implement a model for evaluating the level of Lean Manufacturing based on fuzzy inference in this company that is in the process of lean transformation and whose organizational culture was not initially established with the pillars of lean manufacturing. To create the model, the entire production process was mapped, the process steps were defined and four of the tools already implemented by the company such as 5S, VSM (value stream map), TPM (total productive maintenance) and SMED (single minute exchange of die) were set as the variables. The model adopted to determine the Lean level was based on computer simulation as a tool based on fuzzy logic. The application of the developed model shows that the assessment of Lean Maturity to be used through the fuzzy methodology proved to be feasible to assist in the desired validations, allowing understanding the impact of each linguistic variable in the research result, pointing out how the Company "MCJV" can use the information obtained to improve the Lean transformation management process. A great advantage of the created model is the possibility of being adjusted to any type of organization, it means that input and output variables can receive other linguistic values. As a future suggestion for research, we can include new entries, such as VOP (voice of process) or PSP (problem solving).*
***Materials and Methods**: The methodology was developed in three phases: 1. Definition of Lean Manufacturing Level Indicators; 2. To set Fuzzy "Inference" System; 3. Experiment with the Proposed Model. Each phase is composed by more stages that will drive the results obtained in the research. The proposed Fuzzy system succeed to show the Lean maturity level through the impact of the lean tools implementation when simulated with the different levels of the input variables.*
***Results**: The rule base of the model resulted in 81 rules for analysis. One of the outputs that can be found in the rule 73 such as IF "5S Tool" = High, "TPM Tool" = High, "SMED Tool" = Low and "VSM Tool" = Low THEN the Lean Maturity = Medium Lean, each applied rule can result in different level of maturity. A medium lean can be an advice about which direction the company should put efforts to improve the path of lean transformation.*
***Conclusion:** The implementation of Fuzzy methodology proved to be feasible to support on the identification of the Lean maturity level giving to the company the opportunity to focus on the tools that need improvement, allowing waste reduction and profit increase.*
***Key Word**: Lean manufacturing; Lean maturity; Fuzzy logic.*

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I. Introduction

In an increasingly competitive scenario, industries need to constantly reevaluate their processes in order to always make them aligned with market demands. There are some guiding factors for decision-making in the industry, among them are those related to productivity, which are considered key factors, as they directly influence market competitiveness. The production process needs to be adequate taking into account the demand for volume, quality, technology and delivery, which generally influence the end customer when choosing the product. In addition to these factors, employee satisfaction related to the workplace, attention to their observations and requests for improvement have a direct impact on the results of a production process, which affects the entire subsequent chain of results.

One of the most used strategies for increasing productivity with a customer focus in industries today is the implementation of Lean manufacturing methodology tools such as waste analysis, implementation of kaizen weeks and value stream map, such principles through a continuous Updating internal policies maintains business competitiveness (DESHMUKH Girish, PATIL Ramesh & DESHMUKH Mona G,2017). One of the fundamental principles of building Lean is the focus on reducing waste and better meeting customer needs. (MICHALSKI; GŁODZIŃSKI; BÖDE, 2022).

There are many quantitative benefits when using Lean tools, such as improvement in production lead time, processing time, cycle time, setup time, reduction of defects and scrap, and overall equipment effectiveness. The various qualitative benefits relate to improved employee morale, effective communication, job satisfaction and team decision-making. As Brandão and Santana (2017) state, after the known result of the Toyota company, the Lean methodology with just in time is no longer limited to aspects of production management, and starts to cover people, quality, materials, line edge, review and improvement of tasks.

Regarding the labor aspect Alefari, Salonitis and Xu (2017) in a study identified that although in general the implementation of the methodology begins on the factory floor, it is important that senior management leads this journey in the initial stages. Considering the exposed scenario and the benefits of the Lean tools presented, the objective is to implement a model for evaluating the maturity level of Lean Manufacturing based on Fuzzy inference. This research was applied in an air conditioning industry located in the Manaus Industrial Complex with the aim of answering the questions addressed in a practical scenario through Kaizen weeks where their impacts and results will be observed. The Kaizen activity is linked to the concept of GEMBA as it must occur where the problem is and the participation of the operational team is essential to visualize the reality and the greatest needs that the process presents. Many problems can be more easily resolved when factory floor employees are involved. (K.M. Krupa, S. Patil & B. Singh, 2022).

II. Material And Methods

This research was carried out on air conditioning industry called MCJV, which is located in the Industrial District of Manaus-AM (Brazil).

For the development and simulations of the Fuzzy Model to evaluate the level of Lean Manufacturing, a computer with an i5 processor, 8Gb of RAM and Windows 10 operating system was used, in addition to information from the continuous improvement team, regarding the implementation of Lean Manufacturing tools in Processes. of Manufacturing.

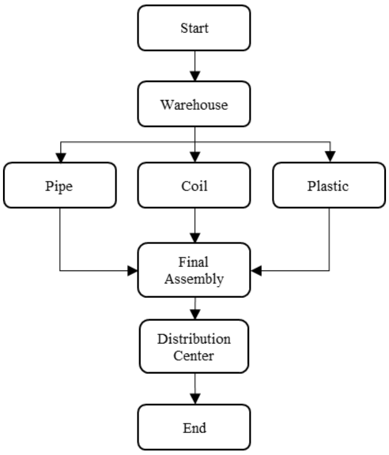
The research Methodological Process was developed in three phases: 1. Lean Manufacturing Level Indicators; 2. Fuzzy "Inference" System; 3. Experiment with the Proposed Model. Each phase composed of three steps: Phase 1 (Mapping of the manufacturing Process, Interviews with Experts and Definition of the Range/Linguistic Value/Numerical Value of each Linguistic Variable); Phase 2 (Development of Fuzzy Sets, Development of "Inference" Rules and Simulation in MATLAB R2016a software); Phase 3 (Compilation of the Indicator Aggregation Algorithm in MATLAB R2016a software, Simulation of Results in 3D and Conclusion). Table 1 demonstrate the methodological process.

Table 1: Methodological Process

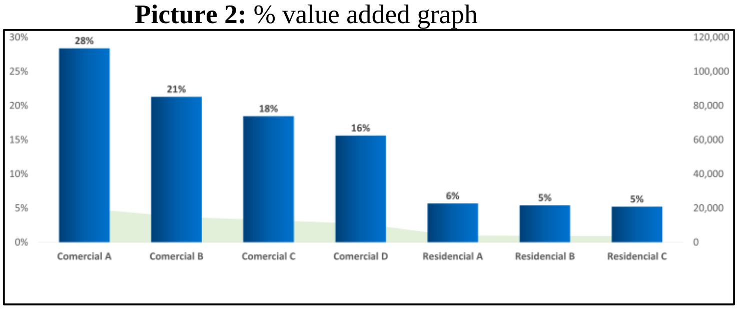
PHASE	STAGE
1. Lean Manufacturing Level Indicators	1.1 Manufacturing Process Mapping of the Company "MCJV"
	1.2 Interview with Experts
	1.3 Definition of the Range/Linguistic Value/Numerical Value of each Linguistic Variable.
2. Fuzzy "Inference" System	2.1 Development of Fuzzy Sets
	2.2 Development of "Inference" Rules
	2.3 Simulation in MATLAB R2016a Software
3. Experiment with the Proposed Model	3.1 Compilation of the Indicator Aggregation Algorithm in MatLab R2016a Software
	3.2 Simulation of Results
	3.3 Conclusion

The commercial air conditioning production area was chosen for this mapping (process flowchart in Picture 1) because it presents the highest added value and the greatest challenge in terms of managing the factory floor due to the size of the products, as shown in Pictures 2 and 3.

Picture 1: Process flowchart



Picture 2: % value added graph



The Table 2 summarize one of the phase 1 main steps which is the Definition of the Range/Linguistic Value/Numerical Value of each Linguistic Variable. In this step we can see the Lean tools identified by the company as implemented and defined as the linguistic variables, this is part of the fuzzification process.

Table 2: Definition of Linguistic Variables

LINGUISTIC VARIABLE	DESCRIPTION	Decorate Range	LINGUISTIC VALUE	NUMERIC VALUE
5S Tool	Application of the 3S of action. Identification of problem sources and implementation of permanent actions. Standardization, Training and Sustainability (Defined periodic audit)	0 - 100 (%)	Low	[0 0 25 50]
			Average	[25 50 75]
			High	[50 75 100 100]
TPM Tool	Assessment of historical data and implementation of temporary actions Identification of problem sources and equipment systems (with closed loop) Identification of a complete spare parts list, implementation of training actions, provision of instructions and a periodic check and preventive maintenance plan.	0 - 100 (%)	Low	[0 0 25 50]
			Average	[25 50 75]
			High	[50 75 100 100]
SMED Tool	Time analysis, identification of critical points and actions. Analysis of internal and external times and implementation of actions Elimination of internal times or transformation into external times, instructions and training.	0 - 100 (%)	Low	[0 0 25 50]
			Average	[25 50 75]
			High	[50 75 100 100]
VSM Tool	Mapping individual processes, identifying problems and identifying actions Partial value stream mapping without counting the company's entire supply and delivery chain. Mapping the entire chain, the impacts between different products and processes and defining improvement actions.	0 - 100 (%)	Low	[0 0 25 50]
			Average	[25 50 75]
			High	[50 75 100 100]
LEAN MATURITY	Level of lean tools implementation – 5s , TPM, SMED, VSM that covers critical areas for efficiency improvement and waste reduction.	0 - 100 (%)	Lean	[0 0 25 50]
			Low Lean	[25 50 75]
			Medium Lean	[25 50 75]
			Lean	[25 50 75]

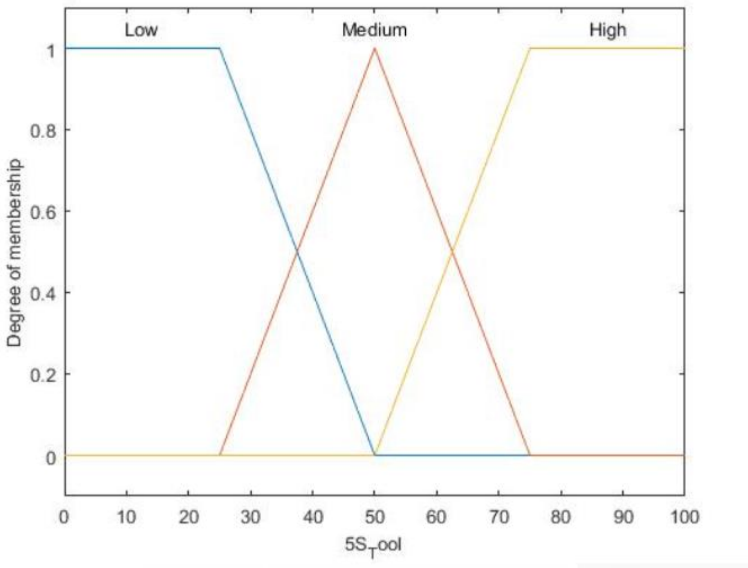
			High Lean	[50 75 100 100]

III. Result

In the Fuzzification process after definition of the linguistic variables the Fuzzy "Inference" System was developed, where Toolbox Fuzzy from the MATLAB R2016a software was used to build the model due to its validation recognized by science. This Fuzzy Model contains 04 Input Variables and 01 Output Variable.

All the linguistic input variables such as 5S Tool, TPM Tool, SMED Tool and VSM Tool constitutes three levels of inference, with trapezoidal and triangular formats. Picture 4 shows the trapezoidal and triangular structures, taking into account linguistic values: Low, Medium, High, according to Table 2.

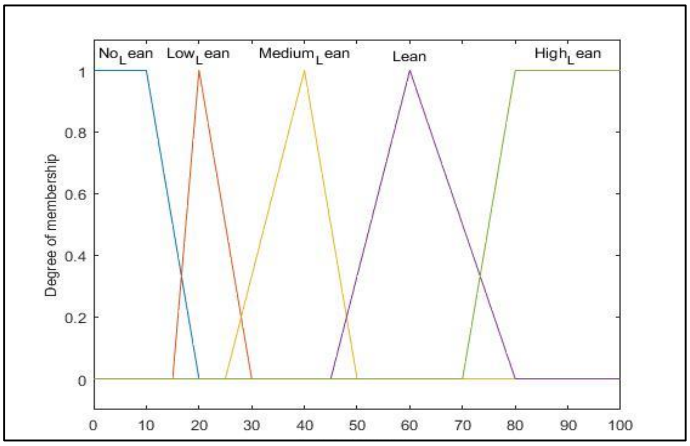
Picture 4: Function for input variables



Defuzzification

The linguistic output variable "Lean Level" constitutes five functions, with trapezoidal and triangular shapes. Picture 5 shows the trapezoidal and triangular structures, taking into account linguistic values: No Lean, Low Lean, Medium Lean, Lean and High Lean according to Table 2.

Picture 5: Function for output variables



Rules base

It still part of the inference system the rules were developed based on the variables and their limits, which resulted in 81 rules for the mentioned problem and for this purpose it was used to relate the IF-THEN type. The IF part defines, whether the rule is valid for the present case or not, in composition, each rule defines the result of the evaluation for the THEN part. In the THEN part, the evaluation result for the rule is defined, generating a linguistic value for the output parameter of the respective inference block represented in the architecture. The set of rules define the procedures for input variables, its format is of the type: If (IF) = antecedent; so (THEN) = consequent. Table 3 presents part of the rule base that was created within the System.

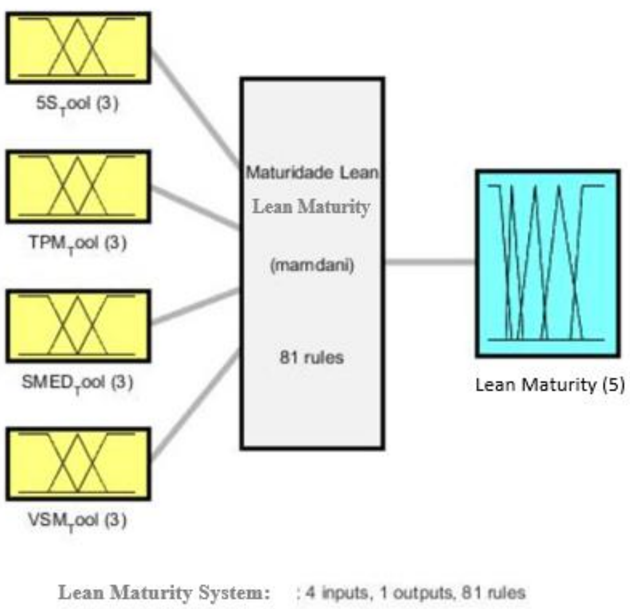
Table 3: Rule base

RULES	INPUT				OUTPUT
	5S	PMS	Decorate SMED	VSM	LEAN MATURITY
1	Low	Low	Low	Low	Not Lean
2	Low	Low	Low	Average	Not Lean
3	Low	Low	Low	High	Low Lean
4	Low	Low	Average	Low	Not Lean
5	Low	Low	Average	Average	Not Lean
6	Low	Low	Average	High	Low Lean
7	Low	Low	High	Low	Low Lean
8	Low	Low	High	Average	Low Lean
9	Low	Low	High	High	Lean Medium
10	Low	Average	Low	Low	Not Lean
. . .					
80	High	High	High	Average	Lean
81	High	High	High	High	High Lean

Simulation/Compilation

After the rule input **process** Fuzzy Toolbox was used for the Simulation/Compilation of the indicator aggregation algorithm. Picture 6 demonstrates the fuzzy controller to obtain Lean Maturity, where the diagram demonstrates the interactions that occur in the controller, with the first blocks corresponding to the 4 input linguistic variables (fuzzification): 5S Tool, TPM Tool, SMED Tool and VSM Tool, which reflect their relevant functions. The middle block shows the 81 resulting rule bases. In the third block, the output relevance function (defuzzification) is presented regarding the Lean Maturity measurement.

Picture 6: Representation of the Fuzzy Controller for Lean Maturity



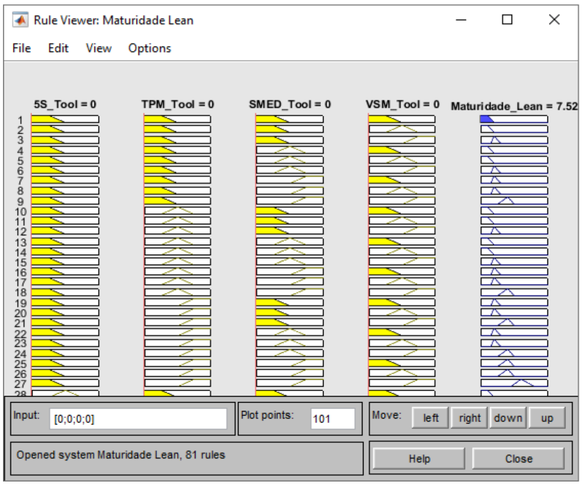
The representation of the Picture 6 was determined based on the set of rules that were applied mathematically, and are connected through linguistic rules based on the knowledge of experts. In this step it was possible to develop an inference system to evaluate Lean Maturity in processes aimed at the Company "MCJV". Distributions were defined for each input variable, essential to guide the degree of pertinence of the functions, to develop a base of rules that allowed the evaluation of decision-making regarding the acquisition of materials. Thus, each variable (5S Tool, TPM Tool, SMED Tool and VSM Tool) demonstrated a trapezoidal and triangular shaped function in accordance with the information entered into the MATLAB system. In defuzzification, 1 variable was used for output (Lean Maturity), the function demonstrated the trapezoidal and triangular format, and highlighted the values for the output variable, based on Lean Maturity.

With the defined rules and previously developed functions the following situations can be demonstrated as examples for the 5 Lean Maturity Levels.

No Lean

According to the picture 7 the variables 5S Tool, TPM Tool, SMED Tool and VSM Tool are at Low Level (0), thus having the same influence on the Lean Maturity of the Production Process, perceived during the simulation of combining the variables, representing 7.52%. According to the rule viewer in Figure 4.3, rule 01 was activated, as follows, IF "5S Tool" = Low, "TPM Tool" = Low, "SMED Tool" = Low and "VSM Tool" = Low , THEN Lean Maturity = Non-Lean, where this scenario indicates that the Production Process does not have any Lean Manufacturing Tool applied.

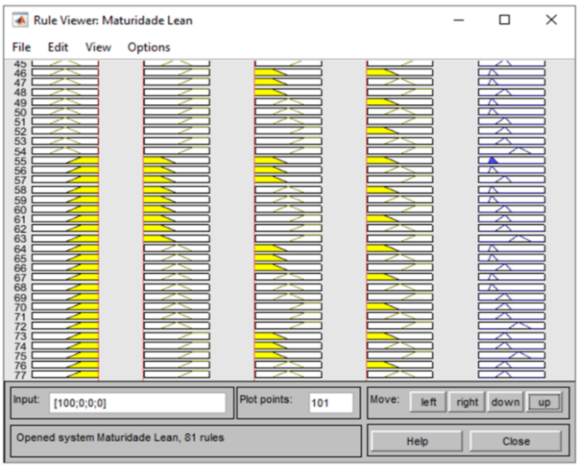
Picture 7: Lean Maturity Chart – No Lean



Low Lean

In relation to Picture 8, the rules graph represents Lean Maturity at a Low Lean level, since the index was 21.70%, representing that in the Production Process there is already a Lean Tool implemented. In this case, rule 55 shows the following form, IF "5S Tool" = High, "TPM Tool" = Low, "SMED Tool" = Low and "VSM Tool" = Low THEN Lean Maturity = Low Lean and the linguistic variables They were as follows: "5S Tool" (100), "TPM Tool" (0), "SMED Tool" (0), "VSM Tool" (0). Based on this Lean Maturity was at a Low Lean level, since the index was 21.70%, which represents an initial Lean Maturity scenario.

Picture 8: Lean Maturity Chart – Low Lean



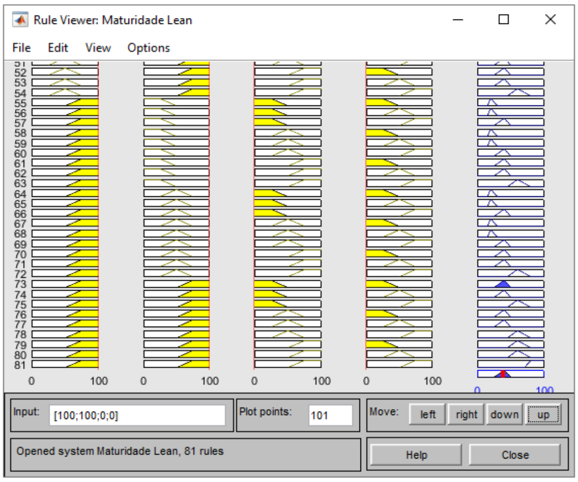
Medium Lean

In the Picture 9 the rules graph represents Lean Maturity at the Lean Medium level, since the index was 38.30%, representing that the Production Process already has Two (02) Lean Tools implemented.

In this case, rule 73 shows the following form, IF "5S Tool" = High, "TPM Tool" = High, "SMED Tool" = Low and "VSM Tool" = Low THEN Lean Maturity = Medium Lean and the linguistic variables They were as follows: "5S Tool" (100), "TPM Tool" (100), "SMED Tool" (0), "VSM Tool" (0).

Based on this panorama, Lean Maturity was at the Medium Lean level, since the index was 38.30, which represents an intermediate scenario in Lean Maturity.

Picture 9: Lean Maturity Chart – Medium Lean



Lean

In relation to Picture 10, the rules graph represents Lean Maturity at the Lean level, since the index was 61.70%, representing that the Production Process already has Three (03) Lean Tools implemented.

In this case, rule 79 shows the following form, IF "5S Tool" = High, "TPM Tool" = High, "SMED Tool" = High and "VSM Tool" = Low THEN Lean Maturity = Lean and the linguistic variables were as follows: "5S Tool" (100), "TPM Tool" (100), "SMED Tool" (100), "VSM Tool" (0).

Based on this panorama, Lean Maturity was at Lean level, since the index was 61.70%, which represents a scenario where the Production Process is at a level very close to Lean Maturity.

Picture 10: Lean Maturity Chart – Lean

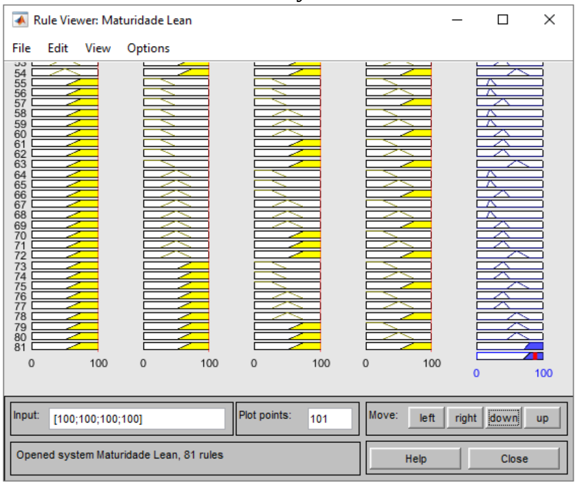
High Lean

In relation to Picture 11 the rules graph represents Lean Maturity at a High Lean level, since the index was 87.60%, representing that all Lean Tools are already implemented in the Production Process.

In this case, rule 81 shows the following form, IF "5S Tool" = High, "TPM Tool" = High, "SMED Tool" = High and "VSM Tool" = High THEN Lean Maturity = High Lean and the linguistic variables They were as follows: "5S Tool" (100), "TPM Tool" (100), "SMED Tool" (100), "VSM Tool" (100).

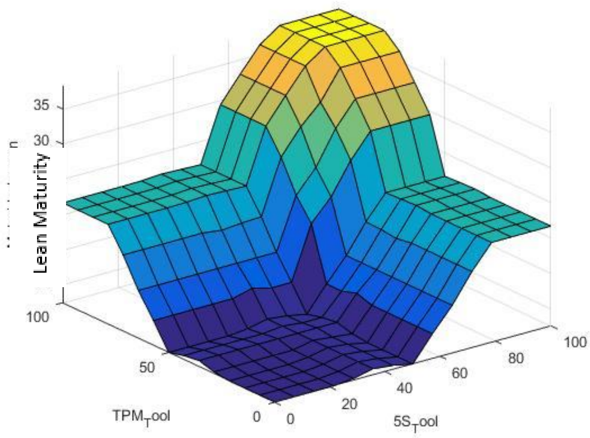
Based on this panorama, Lean Maturity was at a High Lean level, since the index was 87.60, which represents an ideal scenario for a Production Process, as several wastes have already been eliminated as consequence of lean tools implementation and thus ensuring greater stability of the process.

Picture 11: Lean Maturity Chart – Medium Lean



Picture 12 presents the simulation of the results in 3D, which allows observing the analysis of the behavior of the variables, and adjusting the Fuzzy sets and the "inference" rules, in order to express the characteristics presented by the experts, during the modeling of the problem.

Picture 12: 3D Graph



Picture 12 shows that the level of implementation of the 5S Tool and TPM Tool variables directly influence the Lean Maturity of the Production Process. As the tools are implemented in the Production process, the level of Lean Maturity tends to increase. The Company "MCJV" currently does not have a structured procedure for measuring the Lean Maturity of the Production Process, occasionally the evaluation is carried out in a non-experimental way, that is, in the organization's daily experience or through online audits with specialists from the headquarters who evaluate through their experience, these audits are not standardized and may or may not occur once a year with a duration of 8 to 16 hours where a score is generated for the company based on its maturity level.

Through research, the scenarios that resulted in High Lean Maturity level demonstrate that the company must always seek to improve its process by strengthening the implementation of tools in order to eliminate problem sources and improve its production efficiency. Regarding the database, it can be improved as new experimental data to be modeled emerges.

IV. Conclusion

Based on the Manufacturing Process Flowchart and interviews with experts, it was possible to identify the most significant variables and establish the specification requirements of the Fuzzy model for evaluating the production process. With the most significant input and output variables in hands it was possible to create mathematical models to evaluate the optimal level of Lean Maturity, and thus develop the Fuzzy inference rules for the maturity level model.

With the proposed Fuzzy system, it was possible to create five situations “No lean”, Low Lean”, “Medium Lean”, “Lean”, “High Lean”, generated through the inputs of different variations of the level of application of the tools used in the study, two of which presented the possibility of success for the Lean Maturity of the Processes, which allows the MCJV Company to establish parameters to maintain the processes at the Lean or High Lean levels.

The application of the developed model shows that the assessment of Lean Maturity through the application of Lean Manufacturing tools in the Production Process to be used through the Fuzzy methodology proved to be feasible to assist the desired observations, allowing understanding the impact of each linguistic variable in the research results, pointing out how the MCJV Company can use the information obtained to improve its system and consequently its efficiency.

It is worth noting that the study was aimed at just one sector of the company in question, which does not limit the success of applying the Fuzzy method to other environments in the organization.

The approach has the advantage of not requiring a more complex apparatus in relation to mathematical programming, since the data uses the subjective language of classification and the specialist's knowledge to treat and interpret the data. Therefore, it is considered that the initial objective of proposing a different methodology for evaluating the Maturity of Lean manufacturing, which is based on fuzzy logic, has been achieved.

In this scenario, an appropriate use of this technique is suggested with a purpose to evaluate and reach ideal processes in different business segments. The use of Fuzzy Logic therefore constitutes an easy but dynamic tool to achieve faster results on the Lean Maturity of Production Processes.

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