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Application of Fuzzy Logic for Decision-Making in the Criteria for Allocation and Distribution of Industrial Costs.

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Abstract:
Background*: Industries are increasingly specializing in the financial and production sector, aided by general accounting and, especially, cost accounting. Even increasing the degree of complexity of specialized employees, cost accounting in relation to its apportionment criteria is always a challenge. Companies find it very difficult to correctly determine the unit cost of the product or service being offered. And it is precisely at this moment that cost accounting proves to be useful and indispensable. Cost apportionment is one of the branches of industrial accounting and it is a subject that seems to be simple to understand, however, it becomes more complex during your daily practices. This work aims to develop a classification model for decision making based on Fuzzy Logic for diagnosing production performance with a focus on financial improvement based on the optimization of cost apportionment. In this context, the work is justified by pointing out a new perspective of analysis through production and financial indicators implemented in a Fuzzy interference model with the objective of optimizing the apportionment criteria and proposing financial improvements.*

Materials and Methods*: The Methodological Process of the research was developed in three phases: 1. Identification of Economic and Production Indicators; 2. Modeling of the Fuzzy "Inference" System; 3. Proposed Model Experiment. Each phase consists of three stages until reaching the results obtained from the research. The proposed Fuzzy system was able to show the different performance results when simulated with the different conditions of the input variables and which the projected performance classification could be defined.*
Results*: The model resulted in 576 inference rules for analysis. In one of these analyses, I specify analysis 291 according to table 8 of this article, considering the indicator of Overall Labor Effectiveness "Good", Overall Equipment Effectiveness "Bad", Contribution Margin "Good", Breakeven Point "Good" and Liquidity Current "Good", the performance of the product is considered "Medium". With a bad EGE, it is difficult to properly monitor production efficiency to a satisfactory degree, but you can maintain a standard production pace due to the good results of other indicators.*
Conclusion: *In this way, the Fuzzy system helps to guide us in which costing method we should adjust the worked product so that it can generate profitability within the industry and better profit margin, allowing a more critical analysis in internal decision-making.*
Key Word*: Indicators; Apportionment Criteria; Costs; Fuzzy Logic.*

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I. Introduction

Industries are increasingly specializing in the financial and production sector, aided by general accounting and, especially, cost accounting. Even increasing the degree of complexity of specialized employees, cost accounting in relation to its apportionment criteria is always a challenge.
Companies find it very difficult to correctly determine the unit cost of the product or service being offered, and it is precisely at this moment that cost accounting proves to be useful and indispensable.
Cost apportionment is one of the branches of industrial accounting and it is a subject that seems to be simple to understand, however, it becomes more complex during your daily practices. In all companies worldwide, there are always difficulties in optimizing the proportional division of their products and thus achieving the best

profitability. The current industrial market is increasingly competitive and volatile. As a result, competition becomes world-wide and information about costs becomes extremely important for decision-making.

Some research on the topic to be addressed has already been scientifically discussed, but fragmented in relation to the main theme of this dissertation. Bigaton (2018) presents the evolution of common industrial losses and industrial productivity of sugar and ethanol producing plants in regions of Brazil, as well as the association of these factors with the production costs of products and their marketing margins. Associating exactly with the indicators that will be studied, which can cause loss in production and influence product costs.

The scientific contribution of Soares (2020), aimed to apply the Overall Equipment Effectiveness (OEE) in a production system, to monitor and evaluate the situation of the equipment used in the process, highlighting possible improvements. Settanni (2021), also, developed through OEE an integrated analysis, to measure quality indicators of the test process, also provides new perspectives and methodologies for the organization of the workflow of clinical laboratories. It is these improvements that will always be sought through OEE, OLE that will be one of the indicators inserted in the Fuzzy analysis.

In Khatchatourian (2010), a methodology based on Fuzzy Logic was developed for classifying and evaluating the Economic-Financial Performance of production cooperatives. It focused on a comparison of the return on capital and the payment capacity of the productions carried out.

This article implements a new indicator analysis model based on Fuzzy logic to support decision-making on cost apportionment criteria. Production and financial indicators were used in a case study in an industry with some of its products.

In addition to the production indicators of the products; OEE and OLE, financial indexes such as current liquidity, break-even point and contribution margin were used, so that it can be related to the entire context studied, as all this information generated improvements and new investments for industries.

Finally, the methods based on Fuzzy sets or combined with Logic were adapted to the indicators allowing the consideration of quantitative and qualitative factors simultaneously.

II. Material and Methods

The Methodological Process was developed in three phases: 1. Identification of economic and production indicators; 2. Modeling of the Fuzzy “Inference” System; 3. Experiment of the Proposed Model, with its respective steps: Phase 1 (definition of the inference levels of the indicators), Phase 2 (Development of Fuzzy Sets, Development of Rules of “Inference” and Simulation in MatlabR2013 software), Phase 3 (Compilation of Indicator Aggregation Algorithm, Simulation of Results in 3D and Analysis of Obtained Results). Table 3.1 presents the Methodological Process.

Table 1: Methodological Process

PHASES	Description of the STEPS
1. Identification of Economic and Production Indicators	1.1 Definition of inference levels of indicators
2. Fuzzy “Inference” System Modeling	2.1 Development of Fuzzy Sets
	2.2 Development of the Rules of “Inference"
	2.3 Simulation in MatLab R2013a software
3. Proposed Model Experiment	3.1 Compilation of the Indicator Aggregation Algorithm
	3.2 Simulation of Results in 3D
	3.3 Obtained Results

Phase 1: It consisted of identifying the economic and production indicators for the evaluation of a certain product that wants to be evaluated, in which it was adapted to Fuzzy Logic in its result for analysis. This stage aims to identify the potential performance of the product, assess whether it has good operational and financial results or whether the results are irregular in general terms.

Phase 2: The MatLab R2013a software – Fuzzy Toolbox Student version is used to specify the input and output variables, with their respective ranger's, membership function types with their respective linguistic levels.

Phase 3: The results obtained are compiled for the final definition of the product's performance. In the third phase, step 3.1, the software version Student MatLab R2013a – Fuzzy Toolbox was used to compile the indicator aggregation algorithm.

With the experiment, 576 Performance rules were elaborated, individually evaluated by technical criteria, with the purpose of supporting decision-making in the industries and for it to be highly qualified, thereby increasing the performance of the products and optimizing their cost.

III. Result

3.1 Identification and Description of Input Variables – Fuzzyfication

Analyzes of financial and production indicators were identified and described. Table 2 shows the summary of the entire Phase 1 evaluation process.

Table 2: Evaluation Process

INDICATORS	EVALUATION ITEMS	METRICS
1.1 OVERALL EQUIPMENT EFFECTIVENESS (OEE)	Importance of acting on the losses of equipment, as it can lead the company to increase your productivity and efficiency.	BAD: 0 a 50 REGULAR: 45 a 70 GOOD: 60 a 89 EXCELLENT: 85 a 100
1.2 OVERALL LABOR EFFECTIVENESS (OLE)	Evaluate the competence of your employees in their functions within the factory floor.	BAD: 0 a 50 REGULAR: 45 a 70 GOOD: 60 a 89 EXCELLENT: 85 a 100
1.3 CURRENT LIQUIDITY	A company's ability to pay off all of its short-term debts.	BAD: 0 a 0,9 REGULAR: 0,8 a 1,25 GOOD: 1 a 2,5 EXCELLENT: 2 a 3
1.4 CONTRIBUTION MARGIN	What of the Revenue obtained through the sale variables (costs and expenses).	BAD: 0 a 40 REGULAR: 20 a 70 GOOD: 45 a 90 EXCELLENT: 75 a 100
1.5 BREAK-EVEN POINT	Point at which total cost and revenue total are equal, "uniform".	BAD: 0 a 350 GOOD: 250 a 750 EXCELLENT: 600 a 1000

The Fuzzy “Inference” System was developed, with the purpose of aggregating the data for the production of indicators in the criteria: 1.1 Overall Equipment Effectiveness (OEE); 1.2 Overall Labor Effectiveness (OLE); and 1.3 Current liquidity; 1.4 Contribution margin; 1.5 Break-even point.
The system has five inputs and one output. Three input has amplitude in the interval [0; 100], one of [0; 1000] and the last of [0; 3] and the output of [0; 100]. The inputs and output are collected based on the analyzed results. In Figure 3, you can see in more detail the specified Fuzzy inference model, with their respective rangers.

Figure1: Fuzzy inference model

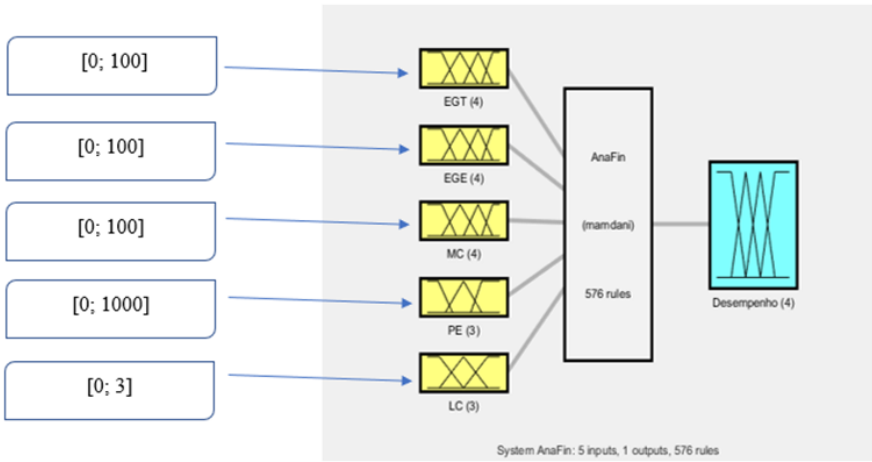


Figure 1 is represented by: EGT is Overall Labor Effectiveness (OLE); EGE is Overall Equipment Effectiveness(OEE); MC is Contribution margin; PE is Break-even point; LC is Current liquidity and DESEMPENHO is Performance.

3.1.1 Overall Labor Effectiveness (OLE) – EGT

Used to measure the improvements made, making it possible to see losses, especially those that generate potential costs. The indicator was based on the result of three indices that represent the reality of the production process, namely: availability, performance and quality.

The linguistic variable "EGT" constitutes four levels of inference, with trapezoidal and triangular formats. Figure 2 presents the trapezoidal and triangular structures, meeting linguistic values: Bad, Regular, Good and Excellent.

Figure2: Membership function for EGT input variable

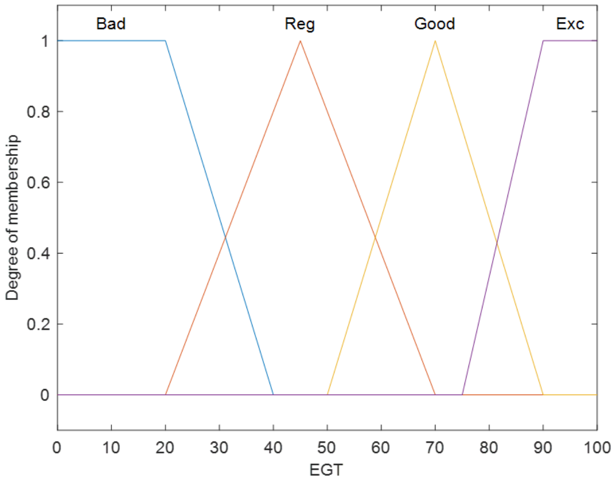


Table 3 shows the values obtained in the fuzzyfication of the pertinence function of the variable "Overall Labor Effectiveness":

Table 3: Numerical Values of the Variable "Overall Labor Effectiveness"

OVERALL LABOR EFFECTIVENESS (OLE)		
LINGUISTIC VALUE	**NUMERIC VALUE**	**FORMAT**
BAD	[0 0 20 40]	trapmf
REGULAR	[20 45 70]	trimf
GOOD	[50 70 90]	trimf
EXCELLENT	[75 90 100 100]	trapmf

3.1.2Overall Equipment Effectiveness(OEE) – EGE

In this indicator it is possible to verify aspects such as: understanding of machine inactivity, delays, absenteeism, etc. It evaluated factors that deal with performance, quality and availability. Thus, the industry is able to assess the competence of its employees in their functions within the factory floor.

The linguistic variable "EGE" constitutes four levels of inference, with trapezoidal and triangular formats. Figure 3 presents the trapezoidal and triangular structures, meeting linguistic values: Bad, Regular, Good and Excellent.

Figure3: Membership function for EGE input variable

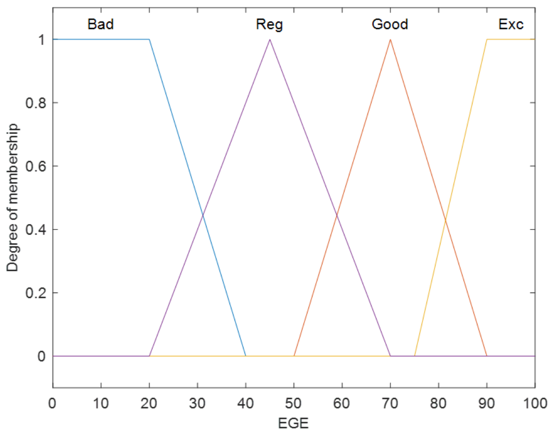


Table 4 shows the values obtained in the fuzzyfication of the pertinence function of the variable "Overall Equipment Effectiveness":

Table 4: Numerical Values of the Variable "Overall Equipment Effectiveness"

OVERALL EQUIPMENT EFFECTIVENESS (OEE)		
LINGUISTIC VALUE	**NUMERIC VALUE**	**FORMAT**
BAD	[0 0 20 40]	trapmf
REGULAR	[20 45 70]	trimf
GOOD	[50 70 90]	trimf
EXCELLENT	[75 90 100 100]	trapmf

3.1.3Contribution Margin – MC

Indicator that demonstrates the amount of money left over from the Revenue obtained through its sale, after removing the value of all variable expenses, composed of variable cost and variable expenses that influence its total cost.

The linguistic variable "MC" constitutes four levels of inference, with trapezoidal and triangular formats. Figure 4 presents the trapezoidal and triangular structures, meeting linguistic values: Bad, Regular, Good and Excellent.

Figure4: Membership function for MC input variable

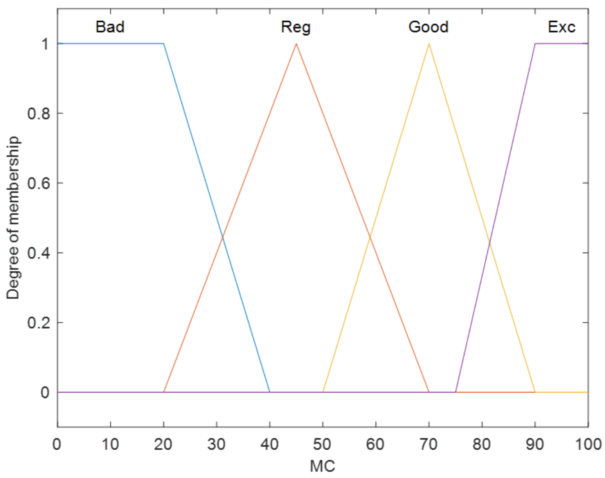


Table 5 shows the values obtained in the fuzzyfication of the pertinence function of the variable "Contribution Margin":

Table 5: Numerical Values of the Variable "Contribution Margin"

CONTRIBUTION MARGIN		
LINGUISTIC VALUE	**NUMERIC VALUE**	**FORMAT**
BAD	[0 0 20 40]	trapmf
REGULAR	[20 45 70]	trimf
GOOD	[50 70 90]	trimf
EXCELLENT	[75 90 100 100]	trapmf

3.1.4Break-even Point - PE

Directly and precisely, the indicator above is the point at which total cost and total revenue are equal, that is, "even". Where it demonstrates the ability of costs to be covered.

The linguistic variable "PE" constitutes three levels of inference, with trapezoidal and triangular formats. Figure 5 presents the trapezoidal and triangular structures, meeting linguistic values: Bad, Good and Excellent.

Figure5: Membership function for PE input variable

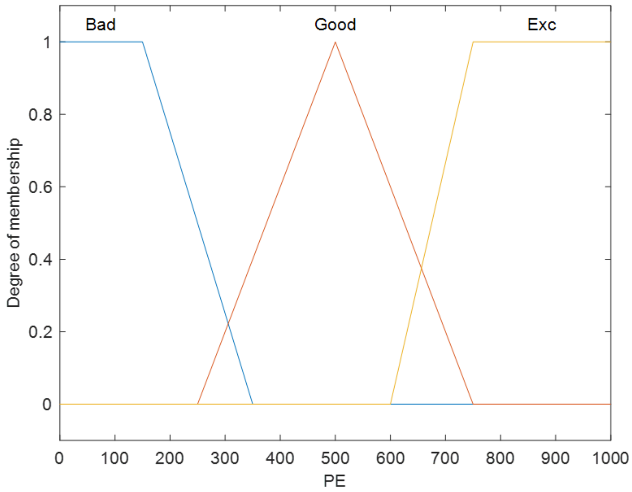


Table 6 shows the values obtained in the fuzzyfication of the pertinence function of the variable "Break-even Point":

Table 6: Numerical Values of the Variable "Break-even Point"

BREAK-EVEN POINT		
LINGUISTIC VALUE	**NUMERIC VALUE**	**FORMAT**
BAD	[0 0 150 350]	trapmf
GOOD	[250 500 750]	trimf
EXCELLENT	[650 750 1000 1000]	trapmf

3.1.5Current Liquidity - LC

It is the ability of a company to pay off all its short-term debt. In theory, it is nothing more than the relationship between the forecast values of cash inflows and also outflows, in this case, over a short period of time.

The linguistic variable "LC" constitutes four levels of inference, with trapezoidal and triangular formats. Figure 6 presents the trapezoidal and triangular structures, meeting linguistic values: Bad, Regular, Good and Excellent.

Figure6: Membership function for LC input variable

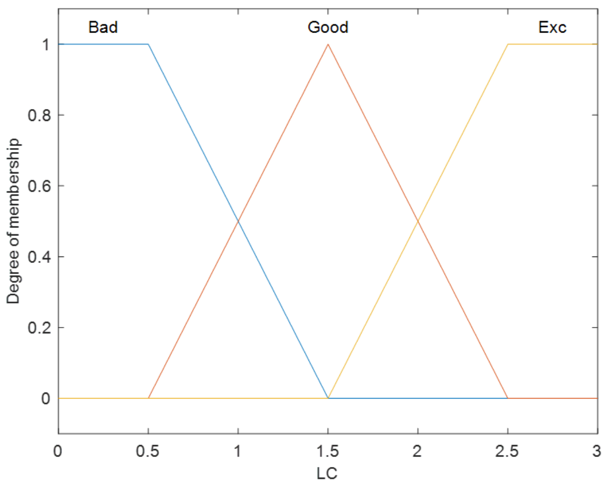


Table 7 shows the values obtained in the fuzzyfication of the pertinence function of the variable "Current Liquidity":

Table 7: Numerical Values of the Variable "Current Liquidity"

CURRENT LIQUIDITY		
LINGUISTIC VALUE	**NUMERIC VALUE**	**FORMAT**
BAD	[0 0 0.3 0.8]	trapmf
REGULAR	[0.3 1 1.7]	trimf
GOOD	[1.2 1.7 2.3]	trimf
EXCELLENT	[71.9 2.3 3.3]	trapmf

3.2Rangers

Table 8 presents the range obtained from the five linguistic variables at the entrance, according to the data in Tables 3, 4, 5, 6 and 7.

Table 8 will demonstrate the range of the five linguistic variables:

Table 8: Range of the five variables

LINGUISTIC VALUE	RANGER
OVERALL LABOR EFFECTIVENESS (OLE)	[0; 100]
OVERALL EQUIPMENT EFFECTIVENESS (OEE)	[0; 100]
CONTRIBUTION MARGIN	[0; 100]
BREAK-EVEN POINT	[0; 1000]
CURRENT LIQUIDITY	[0; 3]

3.3 Conditions for Assessing the Rules

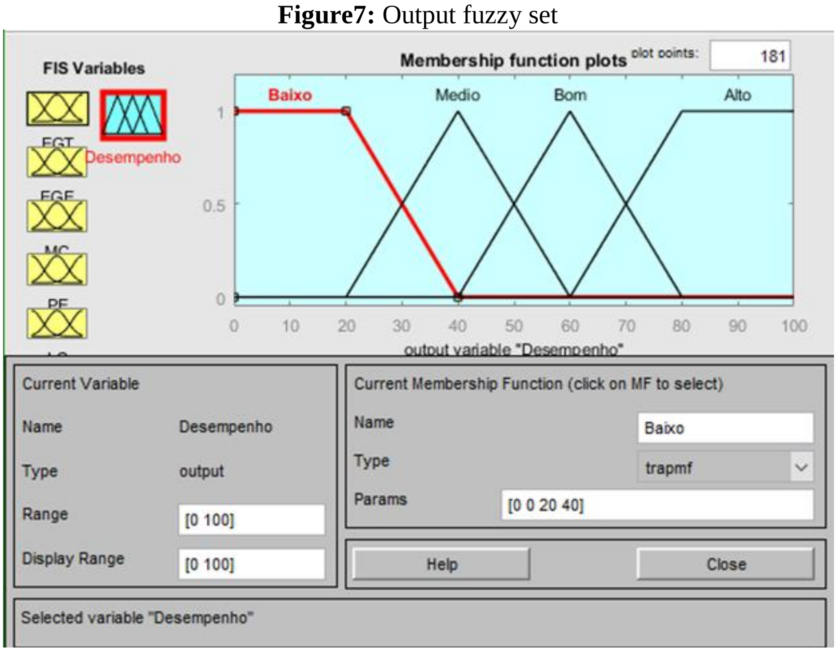
For the rest of the rule bases, it will be used to relate the IF-THEN type. The IF part defines, if the rule is valid for the present study or not, each rule that was established defines the result for evaluation of the THEN part. In the THEN part, the conclusion of the evaluation is used for the rule, generating a linguistic value for the output parameter of the respective inference block represented in the architecture.

The set of rules define the procedures of the input variables, its format is of the type: IF = antecedent = X THEN consequent = Y.

3.4 Identification and Description of Output Variables - Defuzzyfication

In defuzzfication, the controller contains 1 (one) output variable. Figure 7 shows the output (Performance) with a range from 0 to 100. The membership functions used are trapezoidal and triangular, with equidistance between the regions of maximum membership to the sets (apexes of the functions) at "1" on the ordinate axis. The intersections of the functions represent the half membership of each adjacent set, with the value of "0.5" on the ordinate axis. Thus, in Figure 4 the Fuzzy system is visualized. The modeling used the standardized Min-Max operators of Mamdani-type "inference", with "defuzzyfication" by centroid.

Figure7: Output fuzzy set



3.4.1 Product Performance

In this output function, the final performance of a certain product is evaluated, specifying its performance. In this way, it helps decision-making based on several aspects: financial, cost, liquidity, employee and machine. As a result, it is possible to define more precisely improvements in the cost of the product and to define in a more efficient way its apportionment in the internal activities.

The linguistic variable "Performance" constitutes four levels of inference, with trapezoidal and triangular formats. Figure 8 presents the trapezoidal and triangular structures, meeting linguistic values: Low, Medium, Good and High.

Figure8: Membership function for the PERFORMANCE output variable

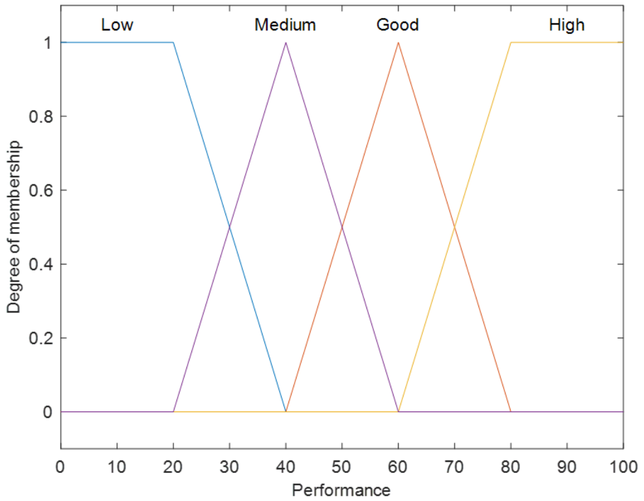


Table 9 presents the values specified for the defuzzification of the membership functions of the variable "Performance":

Table 9: Numerical Values of the Variable "Performance"

PERFORMANCE		
LINGUISTIC VALUE	**NUMERIC VALUE**	**FORMAT**
LOW	[0 20 40]	trapmf
MEDIUM	[20 40 60]	trimf
GOOD	[40 60 80]	trimf
HIGH	[60 80 100]	trapmf

Defuzzyfication made it possible to map the pertinence functions of the Product Performance variable, as shown in Figure 8 and Table 9, showing accurate information regarding Decision Making and translating the sets into fuzzy logic format.

IV. Discussion

In Table 10, a sample of 25 rules was selected out of the 576 elaborated by the experiment, which had a greater variation in performance results for better exemplification and strategic analysis.

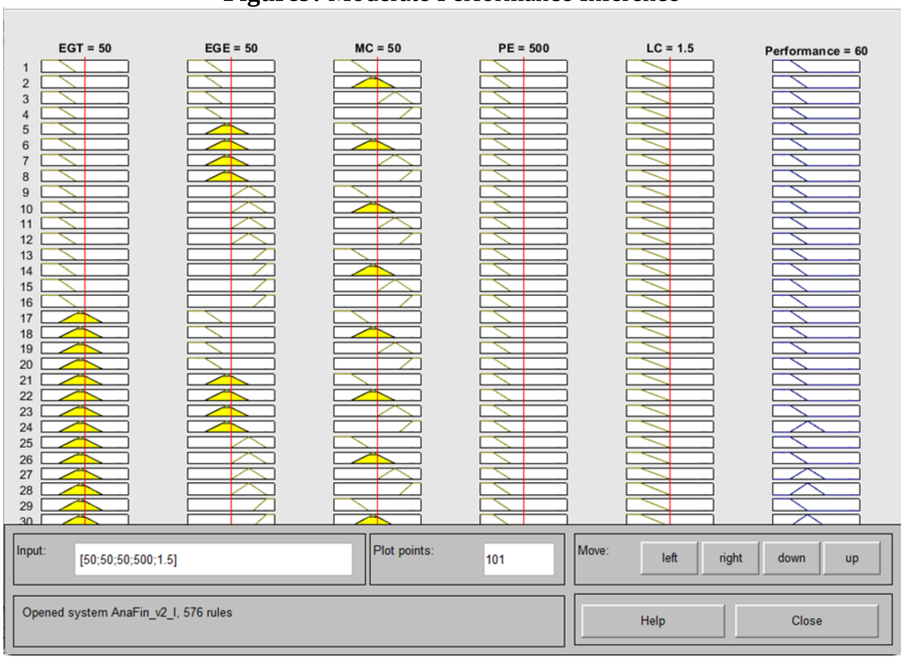
Table 10: Inference rules

SQ.	OLE	OEE	CM	BP	CL	PERFORMANCE
287	Reg	Exc	Good	Good	Good	Good
288	Reg	Exc	Exc	Good	Good	Good
289	Good	Bad	Bad	Good	Good	Low
290	Good	Bad	Reg	Good	Good	Medium
291	Good	Bad	Good	Good	Good	Medium
292	Good	Bad	Exc	Good	Good	Good
293	Good	Reg	Bad	Good	Good	Low
294	Good	Reg	Reg	Good	Good	Good
295	Good	Reg	Good	Good	Good	Good
296	Good	Reg	Exc	Good	Good	High
297	Good	Good	Bad	Good	Good	Low
298	Good	Good	Reg	Good	Good	Good
299	Good	Good	Good	Good	Good	High
300	Good	Good	Exc	Good	Good	High
301	Good	Exc	Bad	Good	Good	Low
302	Good	Exc	Reg	Good	Good	High
303	Good	Exc	Good	Good	Good	High
304	Good	Exc	Exc	Good	Good	High
305	Exc	Bad	Bad	Good	Good	Low
306	Exc	Bad	Reg	Good	Good	Medium
307	Exc	Bad	Good	Good	Good	Medium
308	Exc	Bad	Exc	Good	Good	Good
309	Exc	Reg	Bad	Good	Good	Low
310	Exc	Reg	Reg	Good	Good	Good
311	Exc	Reg	Good	Good	Good	Good

SQ = Rule Sequential; OLE = Overall Labor Effectiveness; OEE = Overall Equipment Effectiveness; CM = Contribution Margin; BP = Break-even Point; CL = Current Liquidity.

After the imputation of rules, the results are simulated in the MatLab software, identifying the performances diagnosed with moderate inference, with poor definition and with excellent definition of result. With these simulations, it is possible to have a broader view of the situation in which each indicator interferes with the Output of the study.

Figure9: Moderate Performance Inference



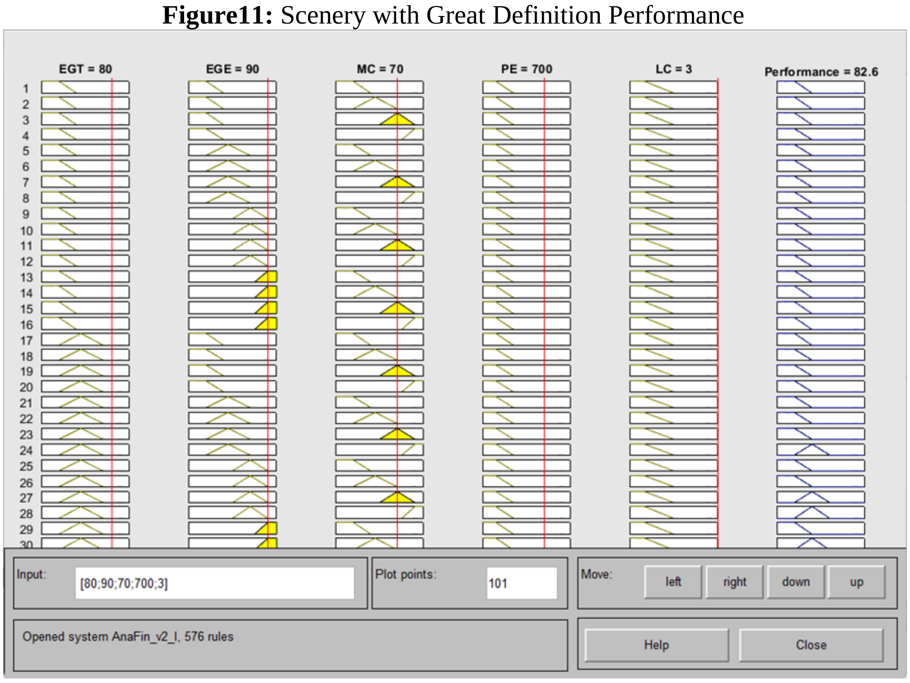
In Figure 9 it is possible to observe that when the EGT indicator is defined as 50 (Moderate), the EGE indicator is defined as 50 (Moderate), the MC indicator is defined as 50 (Moderate), the PE is defined (Moderate) and finally the LC indicator is defined as 50 (Moderate), the product performance will also be identified as moderate

= 60. Therefore, Figure 9 represents that the product performance will be unchanged and at a moderate level when all performances are kept at an intermediate level.

Figure10: Low Performance Scenario

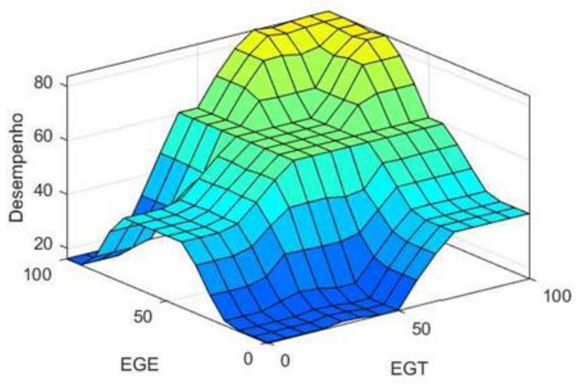
In Figure 10, it is possible to observe that poor definition of the indicators EGT = 10, MC = 20, PE = 300 and LC = 1.5 has a relevant impact on performance, even if EGE is maintained as an intermediate definition. This result negatively influences the level of performance achieved by the product, dropping from 60 of the intermediaries to a performance = 18.5 in an ill-defined scenario.

Figure11: Scenery with Great Definition Performance



In Figure 11, it is possible to observe a high level of definition of the indicators studied, with EGT = 80, EGE = 90, MC = 70, PE = 700 and LC = 3. These results raise the level of performance of the product that is the output studied in this research. It makes the performance reach 82.6%, generating a very high level of quality that the product can generate within the industry. Not only dealing with quality, but also dealing with the economic benefits that the product will bring, being able to work with more precision in its most adequate costing method and that generates even more a high financial return.

Figure12: Analysis of the behavior of the variables (3D Graph)



Step 3.2, later, presents the simulation of the results in 3D, which allows observing the analysis of the behavior of the variables, as shown in Figure 12 (3D Graph), and adjusting the Fuzzy sets and the "inference" rules, in order to express the characteristics presented by the specialists, during the modeling of the problem. Emphasizing that this modeling presented above is of the Performance (Output) related to the EGE and EGT Inputs and it is possible to generate other analysis models varying the Inputs that were used for the elaboration of the research.

V. Conclusion

The research carried out described and detailed the purpose of the production indicators (Overall Efficiency of the Labor and Equipment) and the economic indicators (Current Liquidity, Contribution Margin and Breakeven Point) so that the analyzes can be made from them. From these indicators, several analysis results were specified: "Bad", "Regular", "Good", "Excellent", for each indicator, with triangular and trapezoidal membership functions. With this, the most significant variables for the research were identified.

The development of the Fuzzy "Inference" System, with the purpose of aggregating the data for the production of indicators in the predetermined criteria, establishing a computational model from the rules to classify the performance of a determined study of a product, allowed to evaluate the optimization of the apportionment of costs.

The Fuzzy system was able to show the different performance results when simulated with the different conditions of the input variables and which the projected performance classification could be defined. The Fuzzy system can be used to direct which costing method is best suited to the product being worked on so that it can generate profitability within the industry and a better profit margin, enabling a more critical analysis in internal decision-making.

The experience of professionals in the area of cost or similar areas brings even more relevance to the study project due to the contribution that specialists can deliver after the study model has been analyzed. More concrete data are extracted from real situations that occur in the internal process of a factory floor. When these research data and the elaborated model are measured by even more qualified professionals, they make the degree of development be leveraged to even higher levels. It is noteworthy that the proposed model can be analyzed even by professionals with less experience, as the research helps to reduce the complexity of the study.

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