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INDUSTIAL PERFORMANCE CONTROL WITH FUZZY LOGIC AND AHP METHODS

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ABSTRACT

Performance monitoring has a crucial role in determining the direction of development and progress of an industrial production unit overtime. For this reason, it is important to establish a system to monitor and synthesize the main parameters that affect performance: Productivity, Quality and Safety. In this study, a multi-criteria methodology of evaluation of the industrial performance in a production unit, it passes by a quantification of the indicators (criteria) chosen and is based on a multi-criteria aggregation. The industrial performance has been evaluated - on a real case - using two approaches: The Analytical Hierarchy Process (AHP) and the Fuzzy Logic System for Multi-Criteria Decision Making (MCDM). The comparison between these two approaches and the limits of use of each approach through the specific results obtained allowed to adopt the most reliable and appropriate weighting method. The important task of the proposed models in this study is to determine the numerical score assigned to each year based on the performance parameters. This study presents a comparative analysis of these two studies, illustrated by a case study of the performance of an industrial plant, in order to choose the most appropriate one.
Keywords: - *Fuzzy Logic, AHP, KPI, Industrial Performance, MCDM.*

1. INTRODUCTION

The methods used in monitoring industrial performance are based on the definition and monitoring of all key indicators (qualitative and quantitative) related to this parameter in order to monitor operational excellence. To achieve operational excellence, managers of industrial production units continuously define and monitor industrial performance indicators (KPIs) that affect production operations, whether quantitative or qualitative. These indicators are elements of analysis and provide a comprehensive overview of the state of the unit at a given moment, as well as an alarm signal in case of failure.

However, there are many performance indicators and it is easy to get lost in them. In manufacturing, time is limited and efforts can be spread across different areas/productivity, quality and safety. Therefore, it is necessary to create a tool that captures all KPIs, tracks performance over time, and determines the direction of the unit's development by comparing it with previous results.

In this article, the monitoring of industrial performance was carried out by creating a single performance parameter that summarizes all indicators, considering the weighting of each indicator. Unlike other methods that treat the issue of industrial performance as an index divided into several separate indicators, two methods are presented here. The first is based on the AHP, an MCDM method developed by Prof. L. SAATY, which allows ranking and weighting each KPI criteria before comparing the current values with the previous ones to determine the direction of evolution of industrial performance.

The second method is a system based on fuzzy logic developed by Prof. M. ZADEH, which allows the ranking of priorities to be calculated directly and compared with the previous values.

In this study, the AHP method is first explained and then the fuzzy logic-based method is presented. Then, the results of the two methods are compared to finally select the most suitable method.

2. . RESEARCH METHODOLOGY

2.1. AHP Method

The Analytic Hierarchy Process (AHP), developed by Professor Thomas L. Saaty, is a multi-criteria decision-making method that decomposes any complex problem into a structured hierarchy of problem objective, criteria, and alternatives to help decision makers choose the optimal.

In our research case the proposed model evaluates the operational excellence of the

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production unit via the comparison of the values of the performance indicators (current values with the previous ones) which serve as the comparison criteria.

The AHP can be applied according to the following steps presented in Figure 1

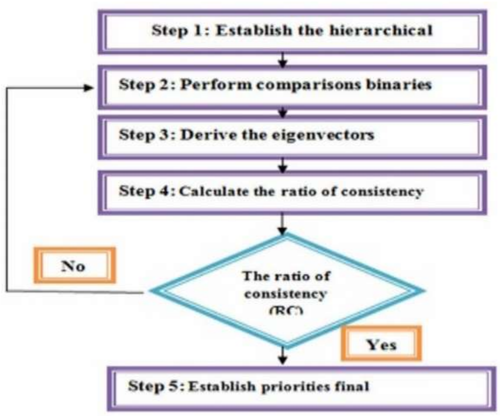

Figure 1 AHP Steps [1].

All the steps presented in Figure 1 will be sufficiently presented in the following sections

2.1.1. set up the hierarchical structure.

At the outset, the overall goal of the decision is stated at the first (top) level of the hierarchy. Specifically, the overall objective of this study is to compare the current performance of the industry with the previous one, based on certain criteria. The second level represents the main decision criteria considered in the selection decision (productivity, quality and safety). The third level represents the sub-criteria for each criterion and the last level of the hierarchy represents the models that form the decision option.

In this study, the models are the current and past performance as shown in Figure 1At the outset, the overall goal of the decision is stated at the first (top) level of the hierarchy. Specifically, the overall objective of this study is to compare the current performance of the industry with the previous one, based on certain criteria. The second level represents the main decision criteria considered in the selection decision (productivity, quality and safety). The third level represents the sub-criteria for each criterion and the last level of the hierarchy represents the models that form the decision option.

In this study, the models are the current and past performance as shown in table 1.

Table 1: Hierarchical Framework.

objective	criteria	Sub-criteria	Sub-criteria Definition	models
INDUSTRIAL PERFORMANCE	Productivity	Productivity rate	The productivity rate is used to measure the performance of resources and the efficiency of processes	the actual industrial performance in comparison with the previous industrial performances
		Production level	The productivity rate is used to measure the performance of resources and the efficiency of processes	
		overall equipment effectiveness (OEE)	The overall equipment effectiveness (OEE) measures the performance of the productive apparatus as a whole.	
	Quality	Rate of compliant products	It is the number of products produced without defects in the first pass.	
		Scrap rate	The scrap rate is used to identify problematic manufacturing processes, the best indicator being the scrap rate per job	
	Safety/ Security	Work accident rate	A high scrap rate can indicate low compliance with instructions, high work rates, etc...	
		Overtime rates	A high scrap rate over an identified period of time can be the subject of a large order, but as a general rule, the workforce is either too small or not distributed properly.	

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2.1.2. perform comparisons binaries

Once a hierarchical framework is constructed, users are prompted to create a pairwise matrix at each level of the hierarchy and then compare each element to the other using the basic pairwise comparison scale as shown in Table 2. «The nine-point scale developed by (Saaty 1980) is accepted by most experts as a very scientific and reasonable basis for comparing two models (Taylor 2010) ». [2].

Table 2: Scale For Pair-Wise Comparison (Saaty 1980)

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

The scale translates pairwise comparative judgments into intensity of relative importance, which is represented by numbers to assess the intensity of preference between two items (Saaty 1980). The judgments are entered with numbers 1, 3, 5, 7, and 9, which correspond to verbal judgments. The values 2, 4, 6, and 8 are intermediate values that can be used to indicate trade-off values of importance between the five basic judgments.

«The comparison matrix indicates the relative importance of the criterion in the columns compared to the criterion in the rows » [3].

For "n" items, the number of comparisons is n(n-1)/2.

For each comparison, authors must decide which of the two criteria is most important and then assign a score to show how important it is.

2.1.3. drive the eigen vectors

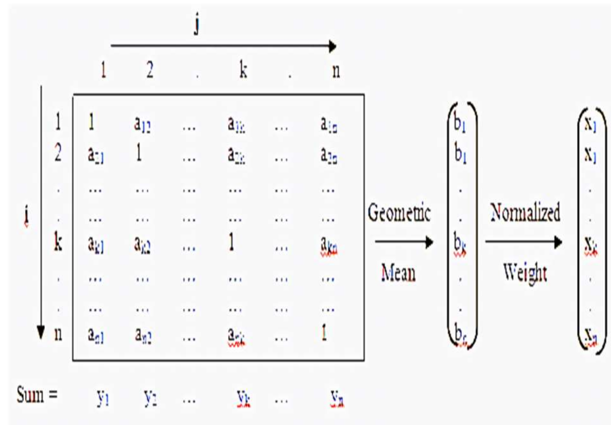

Figure 2. Calculate The Eigen Vectors And Eigen Values.

Here «i» and «j» are the criteria to be compared. «a_{ij} » is a value that represents a comparison between criteria or attributes i and j.

For all values of «i», «j» and «k» in the above judgment matrix, the sum of the elements in a column

$$y_k = \Sigma\, a_{ij}, \text{ where } i = 1, 2... n \text{ and } j = 1,2,$$

The geometric mean is calculated as:

$$bk = [(ak1) *(ak2) *... * (akn)]^{1/n},$$
where k = 1, 2..............n

$$bk = [(a_{k1}) *(a_{k2}) *... * (a_{kn})]^{1/n},$$

The normalized weights are calculated as,

$$X_k = b_k / \Sigma\, b_i$$

2.1.4. calculate the ratio of consistency. Acceptability criteria or attributes are measured in terms of Consistency Ratio (C.R.).

In order to check the consistency of the comparisons made by decision-makers, namely, the matrix A, AHP suggests a technique based on testing the consistency ratio (CR) which is calculated using formula

$$CR = \frac{C.I}{RI} \quad (4).$$

Where consistency measure is given in the form of consistency index (C.I.)

$$CI = (\lambda\, max- n)/ (n - 1) \quad (5)$$

Where λ max is calculated using

$$\lambda max= y_{1x1} + y_{2x2} +......+ y_{kxk}. ......+ y_{nxn}$$
$$\lambda\ max= \Sigma\, y_{kxk} = \text{largest eigenvalue of the} \quad (6)$$

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The following Table gives some randomly generated consistency index (R.I.)

Table-3: Randomly Generated Consistency Index For Different Size Of Matrix

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

- If 0≤CR≤ 0.1, the evaluations made by the decision-maker are consistent.
- If CR > 0.1, the judgment made by the decision-maker is inconsistent; as a result, the evaluations must be revised.

In this hierarchical classification approach, it is also possible to cheque the consistency of our approach by calculating the consistency ratio (CR). The latter is an acceptance test for the weights of the different criteria. This step aims at detecting possible inconsistencies when comparing the importance of each pair of criteria.

2.1.5. establish priorities final

The application of the procedure explained above leads to the results shown in the following table:

Table 4: Pair Wise Comparison Of Criteria.

	Productivity	Quality	Safety /security	norm
Productivity	1	1	3	41.59 %
Quality	1	1	4	45.76 %
Safety / security	0.33	0.25	1	12.63 %
∑	2.33	2.25	8	100%
CR= 0.10.1 ≤ 0.1. so, it's acceptable				

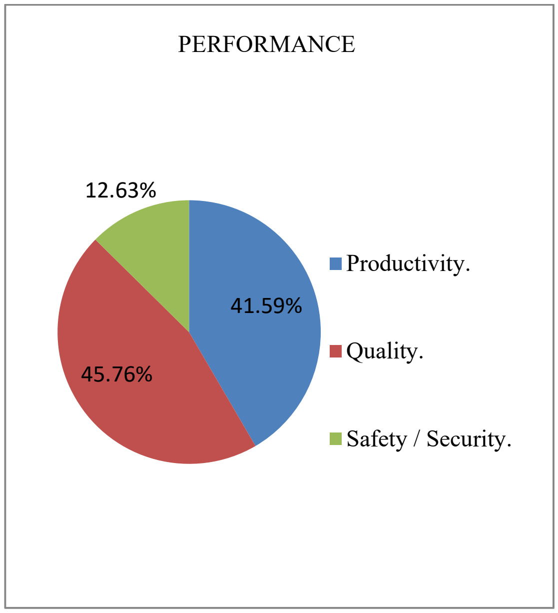

Figure 3: Criteria Weight.

Table -5: Paired Comparison Table To The Productivity Sub-Criteria.

	Production level	Productivity rate	OEE	Local weights
Production level	1	2	3	52.46 %
Productivity rate	0.5	1	3	33.37 %
OEE	0.33	0.33	1	14.15 %
∑	1.83	3.33	7	100%
CR=0.1 ≤ 0.1. So, it's acceptable				

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Table-6: Paired Comparison Table To The Quality Sub-Criteria

	Rate of compliant products	Scrap rate	Local weights
Rate of compliant products	1	1	50%
Scrap rate	1	1	50%
CR=0 ≤ 0.1. So, it's acceptable.			

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Table-7: Paired Comparison Table To The Safety/Security Sub-Criteria.

	Work accident rate	Overtime rates	Local weights
Work accident rate	1	3	75%
Overtime rate	0.33	1	25%
CR=0 ≤ 0.1. So, it's acceptable			

Thus, the global weight of a sub criterion is obtained by multiplying the local weight of the sub criterion by the weight of the criterion

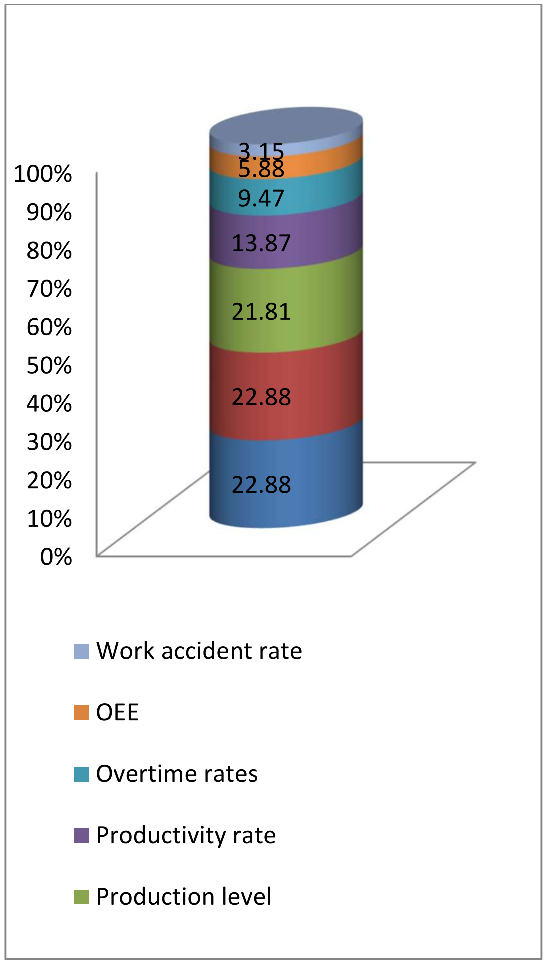

Figure-4: Sub-Criteria's Global Weights

2.1.6. evaluate models

In this step, the experts compare the current KPI values with the previous values using the same approach as the comparison described above. In our case study, we used the annual historical data of an industrial unit for comparison.

Table-8: Industrial unit Historical data

KPI	2017	2018	2019
Production level	7200000	560000	820000
Productivity rate	0.770	0.890	0.800
OEE	0.700	0.790	0.700
Rate of compliant products	0.860	0.950	0.900
Scrap rate	0.079	0.085	0.090
Work accident rate	0.028	0.040	0.051
Overtime rates	0 .200	0.100	0.150

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Table-9: Evaluate Models According To Production Level.

Production level				
	2017	2018	2019	Priority vector
2017	1	3	0.5	32.02
2018	0.33	1	0.25	12.26
2019	2	4	1	55.71
λ_{max} =3.023; CI=0.011 and CR= 0.02 ≤ 0.1. So, it's acceptable				

In this table above, we have compared the values of the d productivity level indicators during the years 2017, 2018 and 2019.

The value of the CR =0.02 what is inferior to the only 0.1 which reflects the coherence and the degree of accuracy of the calculation.

Table-10: Evaluate Models According To Productivity Rate.

Productivity rate				
	2017	2018	2019	Priority vector
2017	1	0.33	0.5	15.92
2018	3	1	3	58.88
2019	2	0.33	1	25.18
λ_{max} =3.07; CI= 0.035 and CR=0.06≤ 0.1. So, it's acceptable				

Table-11: Evaluate Models According To OEE.

OEE				
	2017	2018	2019	Priority vector
2017	1	0.5	1	25
2018	2	1	2	50
2019	1	0.5	1	25
λ_{max} =3; CI=0 and CR= 0 ≤ 0.1. So, it's acceptable				

Table-12: Evaluate Models According To Rate Of Compliant Products.

Rate of compliant products				
	2017	2018	2019	Priority vector
2017	1	0.33	0.5	16.35
2018	3	1	2	53.89
2019	2	0.5	1	29.71
λ_{max} =3.009; CI= 0.004 and CR= 0.007 ≤ 0.1. So, it's acceptable				

Table-13: Evaluate Models According To Scrap Rate.

Scrap rate				
	2017	2018	2019	Priority vector
2017	1	0.5	0.33	16.35
2018	2	1	0.5	29.71
2019	3	2	1	53.89
λ_{max} =3.009; CI= 0.004 and CR= 0.007≤ 0.1. So, it's acceptable				

Table-14: Evaluate Models According To Work Accident rate.

Work accident rate				
	2017	2018	2019	Priority vector
2017	1	4	4	65.50
2018	0.25	1	2	21.13
2019	0.25	0.5	1	13.34
CR=0.067≤ 0.1. So, it's acceptable				

Table-15: Evaluate Models According To Overtime Rate.

Overtime rates				
	2017	2018	2019	Priority vector
2017	1	0.25	0.5	14.28
2018	4	1	2	57.14
2019	2	0.5	1	28.57
λ_{max} =3 and CI=CR= 0≤ 0.1. So, it's acceptable				

Ranking

This step consists of calculating the overall comparison by multiplying the priority criteria and the priorities of each alternative by each criterion. The calculation process is presented below

$$\begin{pmatrix} 0.2181 & 0.1387 & 0.0588 & 0.2288 & 0.0588 & 0.0315 & 0.0947 \end{pmatrix} \times \begin{pmatrix} 0.3202 & 0.1226 & 0.5571 \\ 0.1592 & 0.5888 & 0.2518 \\ 0.2500 & 0.5000 & 0.2500 \\ 0.1635 & 0.5389 & 0.2971 \\ 0.1635 & 0.2971 & 0.5389 \\ 0.6550 & 0.2113 & 0.1334 \\ 0.1428 & 0.5714 & 0.2857 \end{pmatrix}$$

$$= \begin{pmatrix} 0.2157 & 0.3798 & 0.3836 \end{pmatrix}$$

Table-16: Performances Over-All Ranking.

Years	Performance priority	Over-all Ranking
2017	0.2157	3
2018	0.3798	2
2019	0.3836	1

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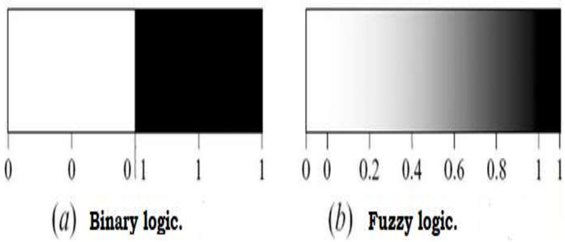
2.2. Fuzzy Methodology for Research Work.

The fuzzy logic is an extension of the Boolean logic (0 or 1), or the truth value of the variable - instead of being true or false- is a real varies between the value 0 and the value 1, it is formalized by Mr. Lotfi ZADEH in 1965, based on the mathematical theory of the fuzzy sets, «the fuzzy logic confers a very appreciable flexibility to the reasonings which use it, which makes it possible to take into account the imprecisions and the uncertainties» [4]..



.Figure 5: Difference Entre Binary And Fuzzy Logics.

The model starts with the data acquisition of the information about the network and the concerned criteria. These data information is modeled with the functions of membership by fuzzification. The Decisions are made by the fuzzy inference through the rules of decision. After the defuzzification, the model suggests strategies of production adjustment like decision classes to expert. They can approve and admit the proposed decisions or propose.

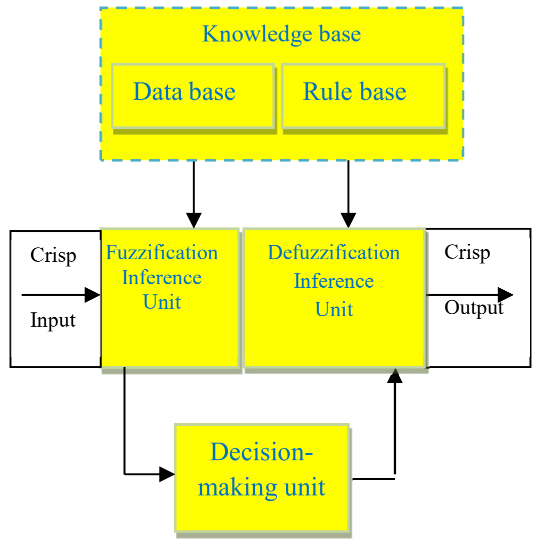


Figure-6. Processus Of Fuzzy Logic.

Step 1: Presentation des parameters

In this section we will use the same parameters mentioned in table 1.

For example, Productivity rate. Production level and overall equipment effectiveness (OEE) directly influence productivity, being the input parameters for the production function. This productivity parameter has an impact on the industrial performance in the production unit.

The same approach will be used for the rest of the parameters indicated in the table

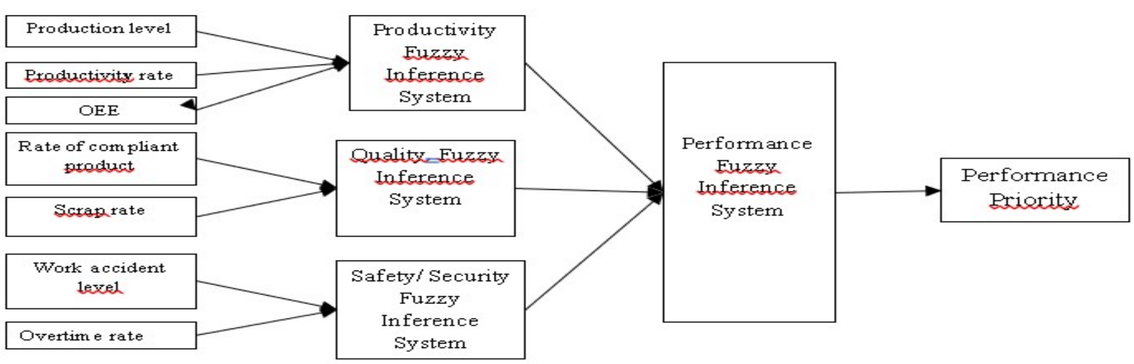


Figure 7. Performance Control System.

Step 1: the conversion of crisp numerical values into fuzzy linguistic values.

Fuzzification consists in setting and dividing the input variables according to functions of normalized membership between 0 and 1 (ordinate axis) and the universe of discourse (abscissa axis) by defining for each variable a function, and for a function of subsets (classes).

The other indicators are modeled using the same principle using membership functions, employing linguistic terms appropriate to each indicator.

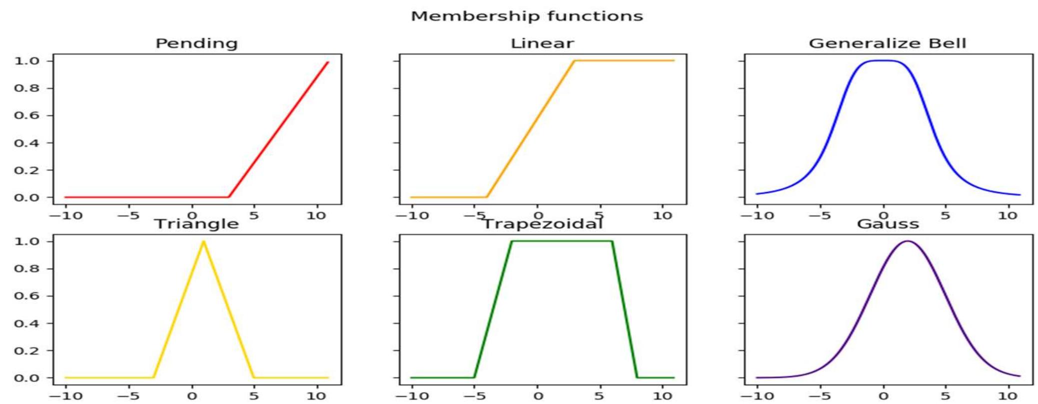


Figure 8. Different Types Of Membership Functions [5].

Step 2: The fuzzy inference system.

A fuzzy inference system is a system that consists of three major building blocks: Fuzzification, Inference engine and Defuzzification.

This research section presents a modern method of performance control through the application of fuzzy logic, which differs from classical logic in that it allows partial or "fuzzy" definitions of decision rules. The strength of fuzzy logic lies in its ability to describe a particular phenomenon or process in language and then represent that phenomenon by a small number of rules. The knowledge and experience base in a fuzzy system is contained in rules and fuzzy sets, which are general descriptions of the properties of the phenomenon in question.

interpretation to the input variables of the decision model. It is necessary to make explicit for each variable in its value interval the different states it can assume. In this approach, a value can be in several groups or several states at the same time. By running the input variables through this fuzzy system, we obtain input variables that we will also consider as fuzzy variables. The inference engine is the step where the decision rules "If..., then..." are parameterized. With the help of this machine, we can apply the rules we have established to our fuzzy input variables.
The last building block of the fuzzy inference system is defuzzification, whose aim is to synthesize the result of the multifactorial decision. In this research, a model of multi-criteria decision making (MCDM) was developed based on the theory of fuzzy logic using the software "MATLAB".
Figure 10 shows how the classification and prioritization of different annual industrial outputs depend on the three KPIs (productivity, quality and safety) that play the role of classification criteria. These in turn vary according to sub-criteria (production level, productivity rate, OEE), (rate of conforming products, scrap rate) and (rate of industrial accidents, overtime rate).

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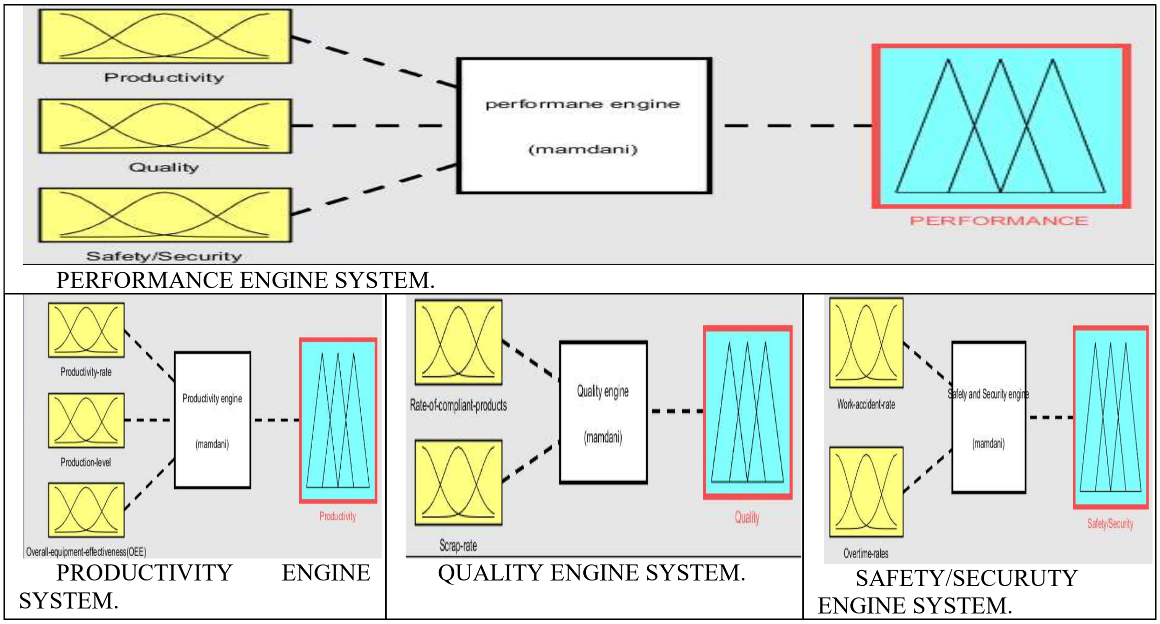

Figure 9. Fuzzy Inference Systems For Each Indicator.

2.2.1. Rule Formation

The rate of compliant products is divided into 3 ranges: Low, Medium, and High, while the reject rate is divided into two ranges: LOW HIGH. So, there are 3X2 = 6 combinations to formulate the rules that affect quality. The same technique is used for the other KPIs, so the results are shown in the following figures.

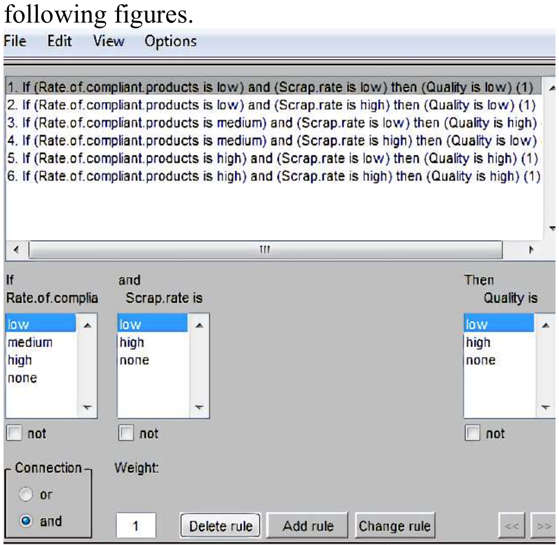

Figure-10: Quality Rules Viewer.

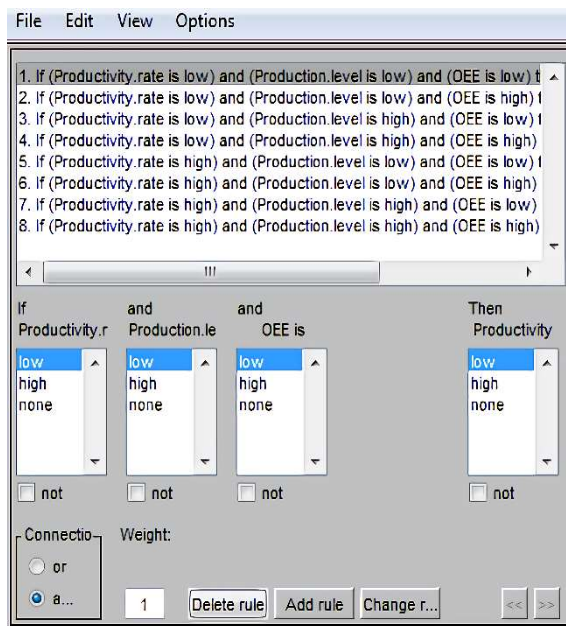

Figure-11: Productivity Rules Viewers.

how it is displayed in the figure above each of the three indicators: productivity rate production level and OEE has two membership functions (high and low) which gives 8 decision rules (2*2*2=8).

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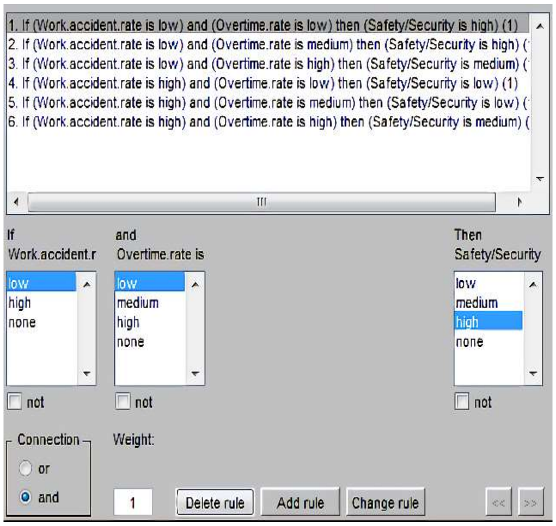

Figure-12: Safety/Security Rules Viewer.

2.2.2. surface viewer

The surface represents the three-dimensional relationship between the various inputs and outputs. The relation depends on the rules worked out. Very random fluctuations of the surface represent the weakness and at the same time indicate the wrong evolution of the elaborated rules.

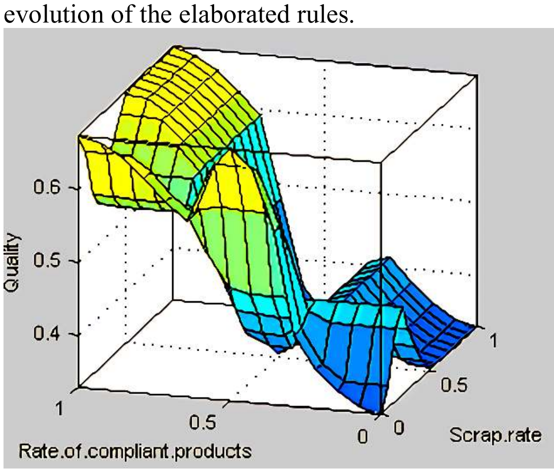

Figure-13: Performance Rules Viewer.

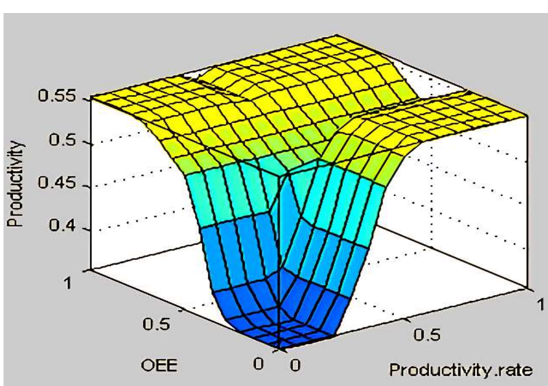

Figure 14: Quality Surface Viewer.

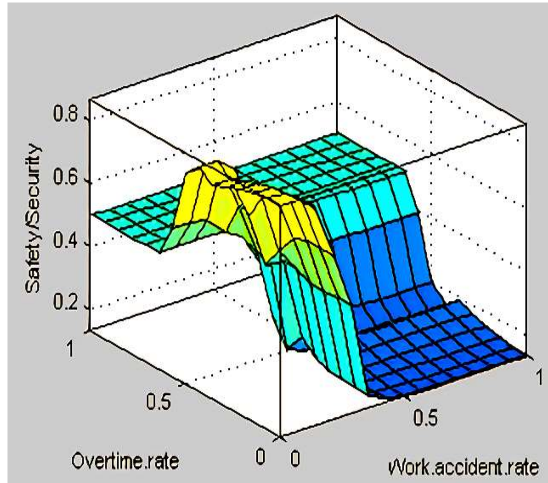

Figure-15: Productivity Surface Viewer.

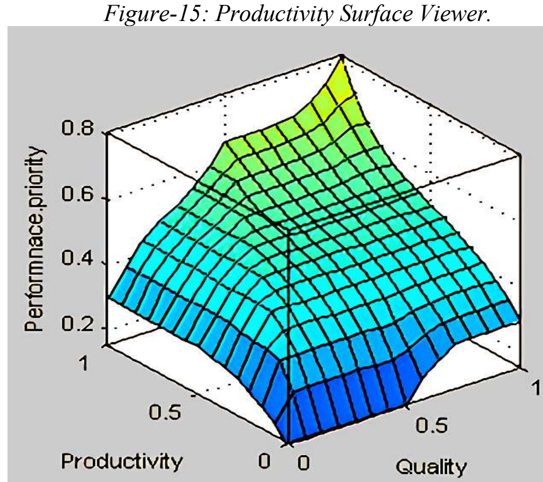

Figure-16: Safety/Security Surface Viewer

The three KPIs discussed above (productivity, quality and health/safety) are reconsidered and used as input variables for global fuzzy inference, where the priority ranking is the result and the corresponding decision rules are determined.

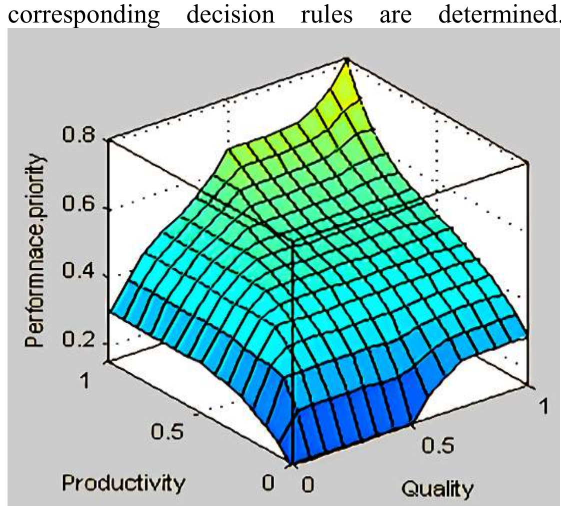

Figure-17: Performance Surface Viewer With Safety/Security Indicator Fixed In Advance: Medium

The interpretation of Figure 11 shows the close relationship between performance and the three parameters: productivity, quality and safety/safety. For example, with a medium safety value, i.e. 0.5, it is clear that performance is low when productivity is low and production quality is low or medium. This output parameter is high when both parameters are high, and it is medium when productivity is low but quality is high, or when productivity is high but quality is low or medium.

With a simulation program, the calculations are extremely precise and can consider many parameters for a very thorough study of the proposed model. With a "simple" computer and a numerical simulation program, it is possible to test the different scenarios. All these dependencies are illustrated with MATLAB

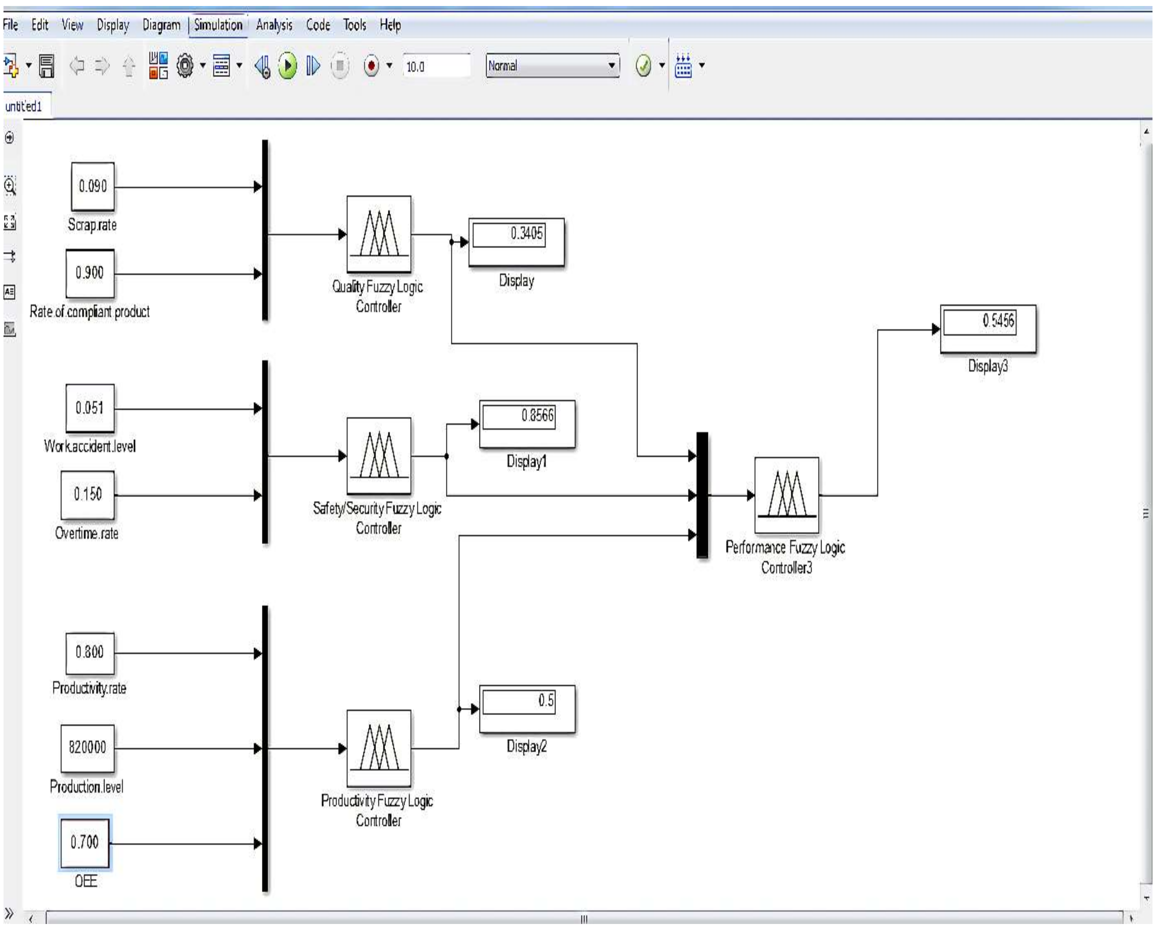

Figure-18: Simulation Of Performance Calculating Using Fuzzy Logic In Simulink.

For the same annual data analyzed in the AHP, the following results are obtained.

Table-17: Performances Over-All Ranking.

Years	Performance priority	Over-all ranking
2017	0.5442	3
2018	0.5450	2
2019	0.5456	1

3. ANALYSIS AND FINDINGS

In this section, the ranking of industrial performance in both methods has been established. This prioritization is based on predetermined input criteria. Fuzzy logic and AHP were used to determine the ranking order.

Table-18 : Ranking Comparaison

Years	Ranking by AHP method: r	Ranking by fuzzy logic method: r'	Difference between ranks d=r-r'
2017	3	3	0
2018	2	2	0
2019	1	1	0

In this comparison between the results obtained by the two methods, it can be seen that Spearman's rank order correlation index is zero, reflecting the correlation of the result. correlation of the result.

$$\rho = 1 - \frac{6\sum di^2}{n(n^2-1)} = 0 \quad (7)$$

Spearman's index represents a tool to compare the results obtained by the two methods AHP and fuzzy logic. In our case of research this index has the value 0 which reflects the coherence of the results, in spite of the difference of methods. The two proposed approaches converge to the same results relative to the performance ranking which represents a parameter measuring the operational excellence.

4. DISCUSSION

From a theoretical point of view, this research work allowed us to establish a new research framework based on the internal dynamics of the production unit to evaluate its operational excellence. The proposed model gives a comparative analysis of the preponderant indicators of industrial performance among all 25 qualitative and quantitative indicators developed by Mr. Cyril MOLINA (2017). To group them in a single parameter entitled "Industrial Performance" using two methods: AHP and fuzzy logic. The first one relies on the evaluation 2 to 2 of the indicators while the second one relies on the decision rules provided by the experts based on experiences and knowledge.

This research framework is a real alternative to the model proposed by Emilie VATTIER (2014) which treats the industrial performance in distinct aspects: quality cost and delay via the tools of lean manufacturing. Also, an alternative to the six-sigma approach adopted by Alain Fernandez (2020) in his work to measure the performance in a production unit. via the DMAIC approach (Define, Measure, Innovate and Control).

The two methods provided us with the same results relative to the ranking of industrial performance in order to evaluate it over time. Nevertheless the choice and the weighting of predominant indicators in all the components of the production this choice remains relative and affects greatly the obtained results and the values allotted to the weights of the criteria of comparison depends on the objectives of each unit of production, indeed, there are units which gives more importance to the quality of these products and there are others which privileges the level of production and the quantity of the products realized by the unit. In the same way, the fuzzy rules used in the method of the fuzzy logic are established by experts according to their knowledge and experiences which vary from one company to another in fact more the historization of data spread out in the time more the exactitude of the results increases so the error is decreased. For example, in our case of study we made the comparison of parameter of the performance during 3 years

It would be interesting to introduce other indicators and to extend the years of analysis instead of 3 years (2017-2018-2019).

5. CONCLUSION

The introduction of a tool that allows the monitoring of the industrial performance of the production site through the comparison between years allows to determine the direction of evolution (upward or downward) in order to adopt corrective strategies to restore and transform the industrial operation within the site. However, the creation of this classification tool is very delicate, as it depends on several criteria and is subject to great uncertainty, which leads farm managers to use imprecise rules and non-scientific comparative tools based on calculations and expertise, which can lead to erroneous results. This can lead to erroneous results and cause the industrial operation not to achieve the desired goals. To remedy this situation, experts need an efficient, manageable and easy-to-use tool for monitoring industrial performance. In this research, two monitoring methods were analyzed to select the best one. methodologies and these are: The AHP method which is possible but not practical as it requires chained calculations which increase the probability of error. The Fuzzy logic method is based mainly on the decision rules developed by experts, so most of the work is done at the beginning to set up these rules after that the result will be displayed directly.

The choice of the method among them is based on the number of factors used in the comparison. Indeed, the more the factors are numerous, the slower the AHP method is and the error associated to the comparison is big and this influence the results. so, the fuzzy logic method will be more adequate in this situation. On the other hand, if the chosen factor is small then in this case the AHP method is more suitable since the error associated with the comparison is small.

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