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THE IMPORTANCE OF FUZZY LOGIC INTEGRATED TO INVENTORY MANAGEMENT: CASE STUDY IN A COMPANY X IN THE INDUSTRIAL DISTRICT OF MANAUS

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ABSTRACT

Inventory management is a practice of fundamental importance for the success of companies in the most varied segments. Companies that operate with low levels of profitability depend on efficient inventory management, under penalty of losing competitiveness. Efficient inventory maintenance is not characterized by the existence of large batches of products for prompt customer service or, on the contrary, by the lack of inventories in an attempt to minimize maintenance costs. Inventories must be managed in a balanced way to ensure an adequate level of service to customers and generate profits. This work aimed to develop a Fuzzy model for stock management of an organization, to reduce the lack of material in stock, resulting from the "lead time". The work is justified by the importance of having a management monitoring the control of inventory costs, which includes the expenses resulting from the lack of items, the costs related to the replacement of the stock, and the expenses of a stopped stock. To accomplish this, it was necessary to map the Material Purchasing Process and thus identify which were the most significant variables in inventory management. The use of Fuzzy Logic, idealized for a model like this, is to reach an inventory level close to zero, immediately before physical replacement, thus minimizing unnecessary costs. Therefore, experimental research aims to manipulate and control the research variables. The application of the developed model shows that the evaluation of Inventory Management through the Need for Replacement of Input and Type of Transport to be used through the fuzzy methodology proved to be viable to assist the desired observations, allowing to understand the impact of each linguistic variable in the research result, pointing out how company X can use the information obtained to improve the structure of its Logistics Process, thus reducing the lack of material in stock due to the lead time.

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INTRODUCTION

Inventory management is a practice of fundamental importance for the success of companies in the most varied segments. Companies that operate with low levels of profitability depend on efficient inventory management, under penalty of losing competitiveness. Efficient inventory maintenance is not characterized by the existence of large batches of products for prompt customer service or, on the contrary, by the lack of inventories in an attempt to minimize maintenance costs. Currently, there has been a constant increase in the demand for healthy foods linked to quality of life and well-being, which has led to the emergence of several business opportunities for those who want to invest in the healthy food market or diversify their operations. According to the international market research agency Euromonitor, in the last five years, the growth of the healthy food and beverage sector was, on average, 12.3% per year and in 2019 the forecast was that the segment would grow even more and reach 50%, moving BRL 110 million (SEBRAE, 2018). It is important that companies in this segment plan to remain competitive in the market. A factor that must be considered in planning is the management of inventories that supply the demands of consumers. With this, it is essential to have full control of stocks, through inventories and the help of various tools, constantly updated so that the productive process of organizations is not affected. Inventories are direct, indirect and patrimonial materials in some quantity, stored in an appropriate place, usually called a warehouse or warehouse. It can be considered as raw material, inputs, materials in production process or finished products. These materials require management based on tools and indicators. Inventory management is essential for the efficient management of materials in organizations, giving them a great competitive advantage, so that their good management provides a service to customer needs, but many organizations have difficulties in maintaining their balance. The work is justified by the importance of having a management monitoring the control of inventory costs, which includes the expenses resulting from the lack of items, the costs related to the replacement of the stock, and the expenses of a stopped stock. The use of Fuzzy Logic, idealized for a model like this, is to reach an inventory level close to zero, immediately before physical replacement, thus minimizing unnecessary costs. The result of the work will emphasize the importance of inventory management for an organization, where it can allocate its resources in the best way ensuring gains in scale and competitiveness. Thus, the main objective of the present work is to develop a Fuzzy model for the stock management of an organization, to reduce the lack of material in stock, resulting from the lead time.

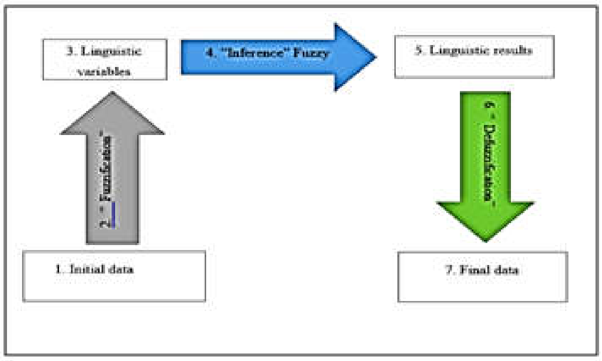
MATERIALS AND METHODS

For the development and simulations of the Fuzzy Model for Inventory Management, a computer with i5 processor, 8Gb of ram and Windows 10 operating system was used, in addition to the Master Planning Worksheet, reports, maps, forms and the Management System used in the Company, where the From there, it was possible to extract and integrate data, as well as information and processes from different sectors, such as sales, purchases, inventory, accounts payable, accounting, etc., all in a single environment.inventory, accounts payable, accounting, etc., all in a single environment. Data collection was carried out in a Company, called X, which is located in the Industrial District of Manaus, where Air Conditioning is manufactured, where it was evaluated during a period of 6 months through on-site visits and monitoring of the execution of the Plan. of Production, which were the main factors that influenced the non-compliance with this, due to lack of materials. We had as input factors, the data of:

- Sales Plan;
- Production plan;
- Production Order Closing Worksheet;
- Minutes of Daily Production Meetings;
- Material Inventory Worksheets;
- Spreadsheet of Rejected Materials by Quality;
- Others.

The Fuzzy Logic System is structured in three steps, as shown in Figure 1, adapted from Cox (1995). In the first step, there is the “fuzzification” (2), in which the transformation of the initial data (1) into linguistic variables (3) takes place, a phase in which all information related to the imprecision or uncertainty associated with these variables must be considered. In the second step, after adjusting the initial values in linguistic variables (3), the Fuzzy “inference” is the next phase (4), whose purpose is to compare the probable variables among themselves by means of pre-established norms, with the goals of the algorithm achieved. From the Fuzzy logic system, “defuzzification” is the third and last step (6) and comprises the interpreted linguistic result (5) of the Fuzzy “inference” methodology in final elements (7), in numerical value (JANÉ, 2004).

However, Cox (1995 apud JANÉ, 2004) gives “defuzzification” another reading (6), in which he interprets the method of transforming a Fuzzy value into a real number. Table 1 presents the Methodological Process of the research, which was developed in three phases: 1. Inventory Management Indicators; 2. Fuzzy “Inference” System; 3. Experiment of the Proposed Model. Each phase is composed of three steps: 1.1 Mapping of Material Purchasing Process; 1.2 Interviews with Experts; and 1.3 Definition of the Range/Linguistic Value/Numeric Value of each Language Variable.; 2.1 Development of Fuzzy Sets; 2.2 Development of “Inference” Rules; and 2.3 Simulation in Matlab R2016a software; 3.1 Compilation of the Indicator Aggregation Algorithm in Matlab R2016a software; 3.2 Simulation of Results in 3D; and 3.3 Conclusion. Step 1.1, Materials Purchase Process Mapping, consists of identifying the Inventory Management indicators for Company X, which are presented as input and output linguistic variables of the stages of the Material Purchasing Flowchart and are significant parts for the progress and fulfillment of the organization's Product Sales Plan.



Source: Cox (1995).

Fig. 1. Fuzzy Logic System

Table 2 presents the input linguistic variables (Productive Demand, Inventory Level and Material Criticality) and output (Input Replacement Need and Transport Type) of the stages of the Material Purchase Flowchart. Step 1.2 consisted of interviewing five experts with experience in the field of Logistics, Production and Fuzzy Logic Consultants, all involved with the improvement of Inventory Management Indicators, obtained in the theoretical framework. In Step 1.3, the Range, Linguistic Value and Numerical Value of each Linguistic Variable were defined, where such information is shown in Table 3. Concluding this First phase, the range, linguistic and numerical value were determined according to the variables obtained from the specialists, as shown in Table 3.3. In the Second Phase, the Fuzzy “Inference” System was developed, where the Toobox Fuzzy of the MatLab R2016a software was used for the construction of the model due to its validation recognized by science. The Fuzzy Model contains 03 Input Variables (Inputs) and 02 Output Variables (Output). To achieve the objectives of this phase, it was divided into three stages, with the first "Step 2.1" transforming the data obtained in the interviews into Fuzzy Sets, where they will be identified and described below:

Inventory Level (IL) – Fuzzyfication: The input linguistic variable “Inventory Level” constitutes three levels of inference, with trapezoidal and triangular formats. Figure 2 presents the trapezoidal and triangular structures, according to linguistic values: Low, Medium, High, according to Table 3.

Productive Demand (PD)-Fuzzyfication: The input linguistic variable “Productive Demand” constitutes three levels of inference, with trapezoidal and triangular formats. Figure 3 presents the trapezoidal and triangular structures, according to linguistic values: Low, Medium, High, according to Table 3.

Material Criticality (MC) – Fuzzyfication: The input linguistic variable “Material Criticality” constitutes three levels of inference, with trapezoidal and triangular formats. Figure 4 shows the trapezoidal and triangular structures, according to linguistic values: Low, Medium, High, according to Table 3.

Need for Input Replacement (NIR) – Defuzzification: The output linguistic variable “Input Replacement Need” constitutes three membership functions, with trapezoidal and triangular shapes. Figure 5 shows the trapezoidal and triangular structures, given linguistic values: Low, Medium, High, according to Table 3.

Transport Type (TT) – Defuzzification: The output linguistic variable “Type of Transport” constitutes three membership functions, with trapezoidal and triangular shapes. Figure 6 presents the trapezoidal and triangular structures, according to linguistic values: Air, Air/Maritime, Maritime OR Land, according to Table 3.

Table 1. Methodological Process

LEVEL	STAGE
1. Inventory Management Indicators	1.1 Material Purchasing Process Mapping
	1.2 Interview with Experts
	1.3 Definition of the Range/Linguistic Value/Numeric Value of each Language 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 of the Proposed Model	3.1 Compilation of the Indicator Aggregation Algorithm in MatLab R2016a Software
	3.2 Simulation of Results
	3.3 Conclusion

Table 2. Definition of Linguistic Variables.

Flow Chart Stage	Description	Linguistic Variable	
		Entrance	Exit
Sales Plan	It is used to promote greater efficiency and precision in defining the strategy of a business, in order to guide your team to make the best decisions. It is the organization's guide in its Productive Planning.	-	-
Master Production Plan	It is a document that contains a list, which presents all the items of a production, as well as when each step will be carried out. This is prepared based on the Sales Plan.	Productive Demand	-
Material Requirements Planning	It is fed by the Master Production Plan, which determines the Products to be produced, where such products have their Bill of Materials, which composes all items and their multiples, and by the Inventory Records. And based on these inputs, it is possible to verify whether the Production Plan can be fulfilled or not.	Inventory Level	Need for Input Replacement
Product Material List	It is the stratification of all materials to be used in the manufacture/assembly of a product, as well as its multiples.	-	-
Inventory Records	It is the availability of each material to be used in the manufacture/assembly of certain products.	-	-
Purchase Order	It is a very important document in supply chain management, as it serves to formalize a commercial proposal to a supplier. With it, the company undertakes to pay for the product it wants to purchase, according to the conditions set out in the budget.	Material Criticality	Type of Transport

Table 3 - Definition Range/Linguistic Value/Numeric Value.

Linguistic variable	Description	Range	Linguistic value	Numeric value
Inventory Level (IL)	It is everything that a company needs to store in order to operate, and can be kept at its minimum, maximum or order point, which is when the organization requests the goods from the supplier at the same time that the customer made the purchase with it.	0 - 100 (%)	Low	[0 0 25 50]
			Medium	[25 50 75]
			High	[50 75 100 100]
Productive Demand (PD)	It is given by the amount of good that buyers want to buy in a given period of time. Demand is not a variable under the supplier's direct control and has a significant impact on the supply chain.	0 - 100 (%)	Low	[0 0 25 50]
			Medium	[25 50 75]
			High	[50 75 100 100]
Material Criticality (MC)	It is the time that refers to a cycle that begins when he places the order and ends when he acknowledges receipt of what he ordered.	0 - 100 (DAYS)	Low	[0 0 15 25]
			Medium	[20 40 60]
			High	[40 70 100 100]
Need for Input Replacement (NIR)	It is the process of replenishing Inputs in Stock in accordance with a Specific Productive Demand.	0 - 100 (%)	Low	[0 0 25 50]
			Medium	[25 50 75]
			High	[50 75 100 100]
Type of Transport (TT)	It is the type of transport to be used for the delivery of the Input, which is chosen according to the level of criticality.	0 - 100 (Dias)	Air	[0 0 15 30]
			Air/Sea	[20 40 60]
			SeaOR land	[40 70 100 100]

In Step 2.2, the "Inference Rules" were developed, and for that, it will be used to relate the IF-THEN type. The IF part defines, whether the rule is valid for the present case or not, in the composition, each rule defines the evaluation result 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 of the input variables, its format is of the type: If (IF) = antecedent; Then (THEN) = consequent. The rule base was developed from the variables and their limits and resulted in 27 rules for the aforementioned problem. In Step 2.3 of the Second Phase and in Step 3.1 of the Third Phase, the MatLab R2016a - Fuzzy Toolbox software was used for the Simulation/Compilation of the indicator aggregation algorithm. In Step 3.2, with the use of Fuzzy Logic, it was possible to develop an inference system for the evaluation of Inventory Management in processes aimed at Company X.

Distributions were defined for each input variable, essential to guide the degree of pertinence of the functions, to elaborate a base of rules that allowed to make the evaluation of the decision making regarding the acquisition of materials. Thus, each variable (Inventory Level, Productive Demand and Material Criticality) showed a function with a trapezoidal and triangular shape in agreement with the information entered in the Matlab system. In the defuzzification, 2 variables were used for the output (Input Replacement Need and Transport Type), the function demonstrated the trapezoidal and triangular format, and evidenced the values for the output variable, based on Inventory Management.

RESULTS AND DISCUSSION

With the rules defined and pertinence functions developed previously, the following situation can be exemplified according to Figure 7, that the variable "Inventory Level" has greater influence on the impact of the Need for Replacement of Input and Type of Transport, perceived during the simulation of the combination of variables, representing 18.90%. And the variables "Productive Demand", "Criticality of Material" have equivalent impact, as they represent 50% of influence on the Need for Replacement of Input and Type of Transport in Inventory Management. activated, as follows, IF "Inventory Level" = Low, "Productive Demand" = Medium, "Material Criticality" = High, THEN Replacement Needs of Input = High and Type of Transport = Air, with this scenario company X would have an immediate need to replace the input and the fastest mode of transport, thus having a high cost, directly impacting Inventory Management.

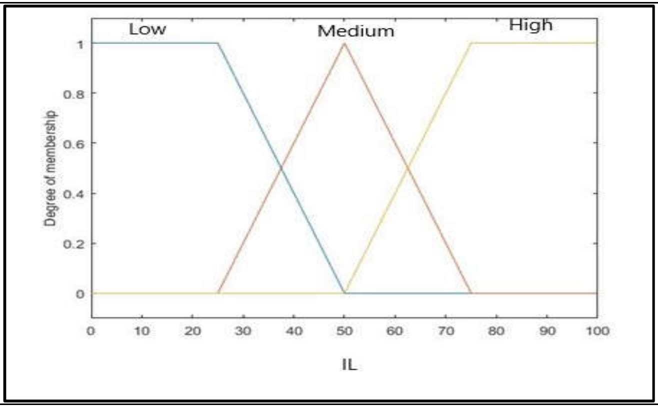


Fig. 2 - Relevance function for input variable IL

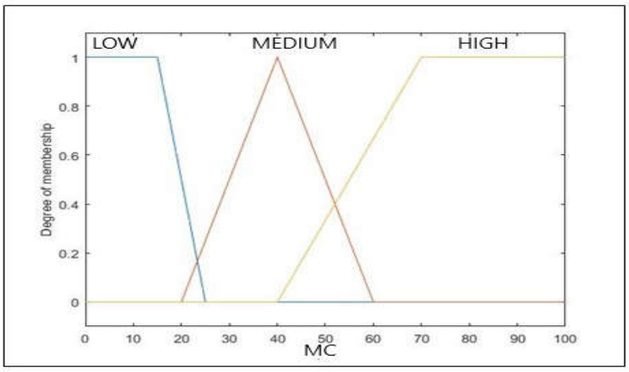


Fig. 3 - Membership function for PD input variable

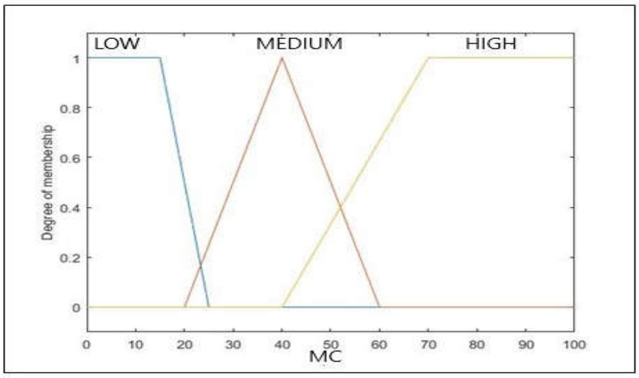


Fig. 4 - Membership function for MC input variable

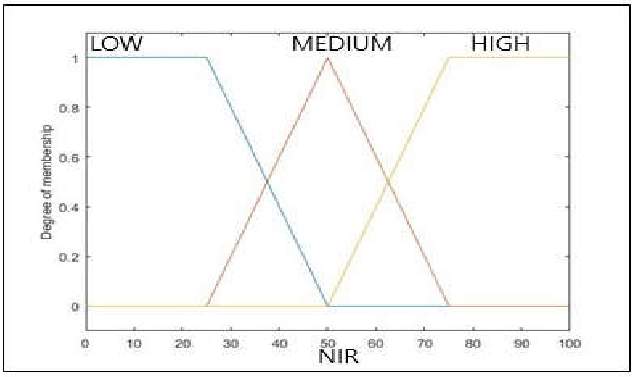


Fig. 5 - Relevance function for NIR output variable

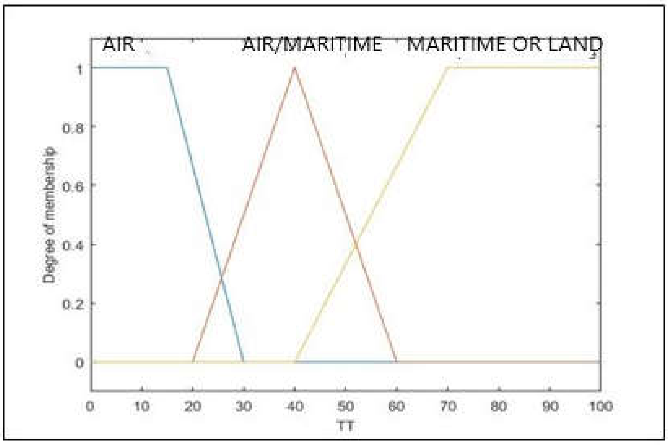


Fig. 6 - Relevance function for TT output variable

Therefore, the value of 78.20% referring to the result of obtaining the Need for Replacement of the Input and 13.00% referring to the result of obtaining the Type of Transport, as shown in Figure 7, exposes the dynamics with the linguistic variables "Inventory Level ", "Productive Demand", "Material Criticality", were compiled during the application of fuzzy logic, representing that information has a significant impact on the final result, which configures that the immediate need in the replacement of the input and in the faster mode of transport. According to the rules viewer in Figure 7, rule 06 was

In relation to Figure 8, the rules chart represents Low Input Replacement Need and Type of Maritime-OWL Transport, since the index was 19.10% and 80.90% respectively, representing an acceptable level of work, in this aspect linguistic values tended to show a favorable scenario for the ideal Inventory Management. In this case, rule 21 shows the following form, IF "Inventory Level" = High, "Productive Demand" = Low, and "Material Criticality" = High THEN Input Replacement Need = Low and Transport Type = Maritime OR Land and the linguistic variables were as follows:

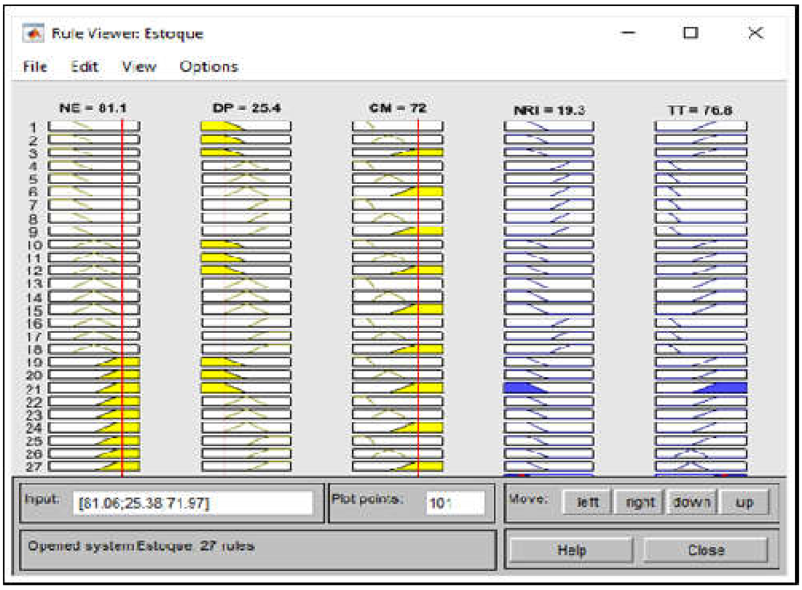


Fig. 7 - Chart of the High NIR and Air TT Rules

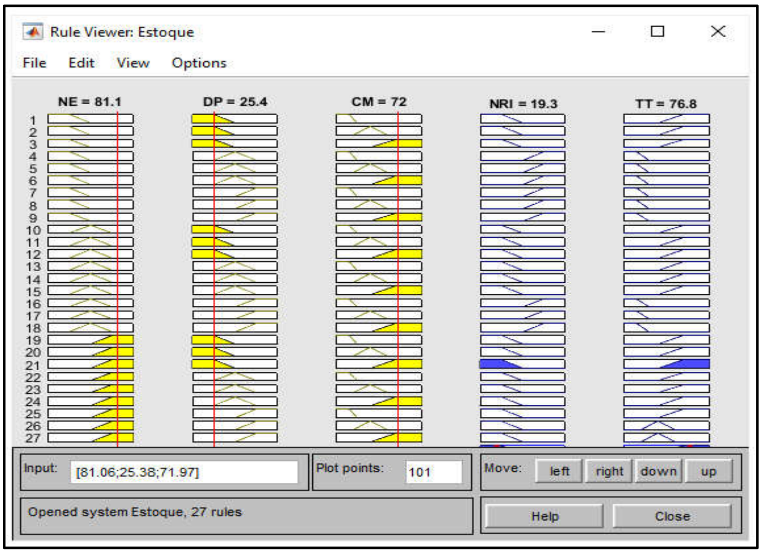


Fig. 8 - Chart of Low NIR and TT Maritime OR Land Rules

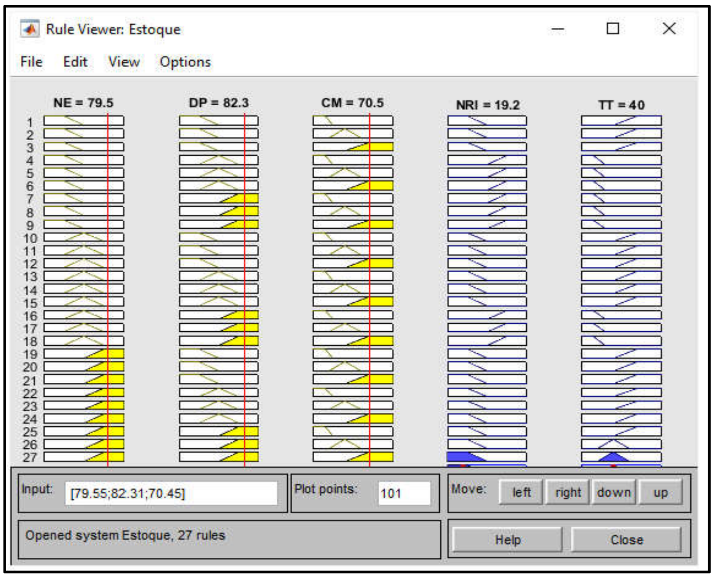


Fig. 9 - Graphic of Low NIR and Air/Sea TT Rules

“Inventory Level” 81.10% impact on the result, “Productive Demand” around 25.40% relevance in the result, “Material Criticality” was 72.00% with respect to the result. Based on this scenario, the Low Input Replacement Need and Type of Maritime OR Land Transport, since the index was 19.30% and 76.80% respectively, is the favorable scenario for company X in Inventory Management.

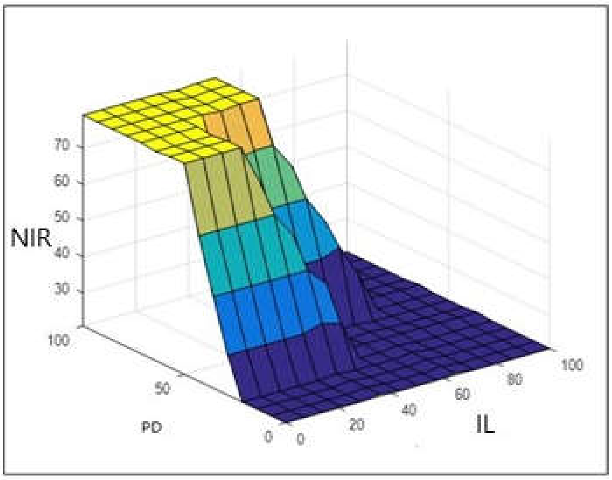


Fig. 10 - 3D Graphic

Figure 9 represents the value of Low Input Replacement Need and Air/Maritime Transport Type, since the index was 19.20% and 40.00% respectively, exposing that the linguistic variables (Inventory Level, Productive Demand and Material Criticality), when well ordered at a high level, generate a process conducive to a somewhat stable Inventory Management.The linguistic variables "Inventory Level" and "Productive Demand" in this scenario, show a variation around 79.50% and 82.30% respectively, "Material Criticality" was around 70.50%, this was reflected in the result favorably since Input Replacement Need was Low.

In this sense, company X would have a strong procedural structure, since the values understood when worked with synergy configure a condition that favors the Ideal Inventory Management, according to rule 27, where SE "Inventory Level" = High, "Demand Productive” = High, and “Criticality of Material” = High THEN Need for Input Replacement = Low and Type of Transport = Air/Maritime.Figure 10 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.Figure 10 shows that the variables IL and PD directly influence the NIR. If the IL is too low, and the DP is too low, the NRI goes down. When IL is low and PD is high, NIR is High. When IL is High and PD is low, NIR is low.Company X currently does not have a structured procedure for measuring the Need for Input Replacement integrated with the Type of Transport to be used in Inventory Management, occasionally the assessment is made in a non-experimental way, that is, in the daily experience of the organization However, the scenarios that resulted in Low Input Replacement Need would be the most suitable for that corporation, as they can reflect how the linguistic variables Inventory Level, Productive Demand and Material Criticality have an impact on achieving the ideal Inventory Management.Regarding the database, it can be improved, as new experimental data to be modeled emerges.

CONCLUSION

From the description of the Inventory Management of Company X, it was necessary to map the entire manufacturing process, so that it was possible to understand which steps had a direct influence, focusing on the objective of reducing the lack of material in stock. This mapping was of paramount importance for the continuity of the research, because from it it was possible to have an overview of what were the inputs and outputs of each stage. From the Material Purchasing Flowchart, it was possible to identify the most significant and relevant variables that from these it would be possible to have a better control over the Inventory Management. With the most significant input and output variables, it was possible to create mathematical models based on Fuzzy Logic to assess the optimal level of stock replenishment, and thus develop the Fuzzy inference rules for the stock replenishment model. The application of the developed model shows that the evaluation of Inventory Management through the Need for Replacement of Input and Type of Transport to be used through the fuzzy methodology proved to be viable to assist the desired observations, allowing to understand the impact of each linguistic variable in the research result, pointing out how company X can use the information obtained to improve the structure of its Logistics process, thus reducing the lack of material in stock due to the lead time.

It was possible to create three situations, two of which presented the possibility of success for Inventory Management, which allows company X to establish parameters for the replacement of materials at the right time. In the third situation, the developed fuzzy inference system made it possible to visualize that the Need for Replacement of Material and Type of Transport will increase the operational cost, so it is necessary to propose actions/controls to minimize the negative impacts of the failure to acquire the material at the moment right. It is worth mentioning that the study was directed to only one sector of the company in question, which delimits the success of the application of the fuzzy method to the other environments of the organization. It is also noted that the 3 linguistic variables are dependent on each other, as none had a direct influence on the achievement of the ideal Inventory Management. The approach has the advantage of not requiring a more complex apparatus with respect to mathematical programming, since the data use the subjective language of classification and the expert's knowledge to treat and interpret the data. Therefore, it is considered that the initial objective of proposing a differentiated methodology for the evaluation of Inventory Management that is based on fuzzy logic had been achieved. To achieve the ideal Inventory Management in its processes, company X must adjust the critical points found during the application of the fuzzy inference system, since these have a relevant impact on the result. In this sense, an appropriate use of this technique is suggested in order to contribute to the improvement and reach of the ideal processes in the various business segments. The use of Fuzzy Logic is, therefore, an easy, but dynamic tool to achieve faster results on your inventory management, thus enabling adaptation to the needs imposed by the market, since it helps the control of materials in order to reduce to the maximum capital invested in the stock.

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