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This paper introduces the concept of fuzzy logic, some terms used in this kind of logic, and uses it to evaluate and choose where to deploy factories and other enterprises. In addition, a model is made using the InFuzzy program to evaluate a choice of a location within the Manaus Industrial Pole - PIM, using objective and subjective criteria within the fuzzy logic. This article aims to present the fuzzy logic in the context of production engineering, select the parameters that define the best location, develop models that represent the subject in the study and verify the applicability by simulating other case studies and comparing results.

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Abstract

This paper introduces the concept of fuzzy logic, some terms used in this kind of logic, and uses it to evaluate and choose where to deploy factories and other enterprises. In addition, a model is made using the InFuzzy program to evaluate a choice of a location within the Manaus Industrial Pole - PIM, using objective and subjective criteria within the fuzzy logic. This article aims to present the fuzzy logic in the context of production engineering, select the parameters that define the best location, develop models that represent the subject in the study and verify the applicability by simulating other case studies and comparing results.

Keywords: Fuzzy logic; Factory location, Inference model;

1. Introduction

Choices in times of globalized and increasingly interconnected economies need speed and precision, hence the need to use all available decision-making tools. Choosing a deployment location is a resource-intensive, time-consuming decision that can bring many benefits or be responsible for the failure of a corporate decision. [19] apud [3], highlight criteria such as: market, transportation, labor, raw material and

government regulation when deciding where to locate a facility. There are still criteria such as cost minimization, distance minimization, local taxes, legal requirements, community attitudes and living conditions as important for site location.

[8] classify two types of factors in locality choices, quantitative factors, those that can be measured, such as fixed costs, personnel costs, and qualitative factors, which cannot be quantified, such as staff attitude and unions, Environmental constraints, political scenario, for these unquantifiable factors, are given grades of grading by the local assessor based on the points defined by the strategic planning.

The concept of the fuzzy set was introduced by Lofti A. Zadeh at Berkeley University in 1965. Zadeh noted that for certain problems that contained ambiguous variables, classical logic and available technological resources were not sufficient to solve problems of a diffuse nature. In search of a solution to this problem, he published an article summarizing the concepts of the fuzzy system, which proposed an extension of classical logic that would act on the real number range [21]. Unlike conventional logic, fuzzy logic admits that values have a degree of relevance, trying to simulate roughly human thinking, which functions differently from the binary form of conventional logic. Taking into account the use of fuzzy logic in the analysis of ambiguous linguistic variables, the analysis of qualitative factors for choosing a locality can be made from the perspective of fuzzy logic to find the best solution for decision making.

This paper aims to present the concept of fuzzy logic introduced by Zadeh, some current applications, as this tool can be used in the context of production engineering and decision making aimed at choosing a location for a factory deployment, also has to objective, assemble a model using the InFuzzy program for demonstration.

2. Theoretical Review

2.1 Geographic localization

[17] states that location is the geographical position in which the operation interacts with other operations or resources. [2] brings the concept of driving force that according to the type of operation the driving force for moulting, is given as an example the location of factories and warehouses that the driving force would be, predominantly, the economic factors, when the operation is directed at retail the driving forces are focused on costs minus the revenue that gives the determination of profit. When the operation is geared to providing a service, public or private, ease of access is a driving force even when it is not easy to determine the revenues and costs of these operations.

2.1.1 Locale-relevant factors

For location of industrial companies [9] states that these companies base their location where resources are most readily available, such as water, raw materials, energy and labor. [11] add tax incentives to factors in choosing a location, highlight the ICMS tax, land donation and paving projects granted by municipalities and states.

Each industrial segment has different characteristics in the production of its product, so each choice of location takes into account the factors that have the best advantage for choosing each company, raw material, electricity, water, labor, tax incentives and proximity. to the consumer market are determining factors for

these ventures.

2.2 Methods for choosing location

When selecting location alternatives for operations installation, two types of data are analyzed: quantitative and qualitative [11]. [8] highlight as quantitative data or objective costs with personnel, equipment, land, water, electricity, transportation, gas, fees and taxes, that is, all that can be quantified. Qualitative data or factors are those that cannot be attributed value, they can only be observed and analyzed. The following stand out: attitude of staff, unions and the community, environmental and governmental restrictions, quality of life, among others. Still regarding qualitative data, they say: it is data about the place that needs to be measured more subjectively, such as climate aspects, quality of life, education level and quality of the workforce and other subjective information.

As a solution for choosing the location based on quantitative data the following methods are used: center of gravity method and break-even method

2.2.1 Center of Gravity Method

It consists of choosing the location taking into account the existing location of customers and key inputs that will determine the costs of transportation and distribution of finished products. The point found represents the geographical point where transportation costs are the lowest possible. If the number of suppliers and customers is very high, it is recommended to use the Pareto chart tool, using the 20/80 ratio in which 20% of customers and suppliers account for 80% of profit, using only 20%. in the location within the generated map. The second step is to survey the volume of inputs / goods transported from the most representative suppliers and customers for the intended location by analyzing the cost of movement. The next step is to apply a grid over the map to assign Cartesian coordinates. The fourth step is the calculation of the center of gravity which represents the ideal location for the installation having two coordinates, one vertical and one horizontal.

2.2.2 Balance Point Method

This model aims to assist in the choice of locality through CLV analysis (cost, value and profit) for each locality being the best alternative to the locality with the highest profit. For the assembly of the model, first is made the separation between fixed and variable costs, being the fixed costs those that remain constant, regardless of the quantity produced already the variable costs are expenses that vary according to the volume produced. The next step is to calculate the contribution or profit margin, after making the cost projections and estimating the price the calculation can be made. The locality with the best profitability index stands out.

The calculation of the breakeven point is important for the production expectation to be analyzed at several chosen points and to compare them with each other based on the different production levels.

2.3 Evaluation of qualitative factors

This method proposes to value subjective characteristics that cannot be quantifiable. In this method the opinion of the evaluators and the subjective data are part of the decision making process so that the choice

of locality is fair and rational [11] and [10]. Previously selected sites receive scores according to the criteria selected by the evaluators based on the most important characteristics for the project. The first step is to identify the factors that are relevant, listed in criteria lists. The list can be very long, so the need to consult technical experts to make the list of criteria as objective as possible and that no relevant items are left out. Then, with the factors already selected, a degree of importance is assigned to each item, the sum of these degrees or weight given to the factors should total 1.0, if not done another step must be taken that is the division by the sum of the weights. The most relevant factors receive lower weights and the less relevant factors receive lower weight. The choice of given weights requires the participation of professionals from different areas of the company, so that the different views are taken into account as the factors have different weight depending on the area that assigns the value. The next step is to rate the pre-selected locations by looking at the factors previously defined, a common scoring scale is given for all factors, ranging from zero to ten or zero to one hundred, with zero being the least favorable location and one hundred or ten most favorable to the goal. The last step consists of weighting the grades, multiplying the weight of each factor by the grade assigned and adding the product to have the grade of the possible location. The location that gets the highest grade will be the location chosen to set up the venture.

3. Using Fuzzy Logic to Choose Locale

3.1 Fuzzy Logic

[4] states that in fuzzy logic a premise has a degree of truth ranging from 0 (zero) to 1 (one), leading the premise to be partially false or partially true, differing from Aristotelian logic that allows only one premise. be either totally true or totally false.

[18] state that the fuzzy concept was presented in the works of Professor Lofti A. Zadeh, with the objective of giving mathematical treatment to subjective linguistic terms such as "very hot", "little cold", "approximately", among others. Zadeh noted that at the time the most modern technological resources were unable to automate ambiguous situations related to problems of an industrial, biological or chemical nature. The versatility of fuzzy logic is given by the ability to mathematically model and manipulate information that is vague or inaccurate, which is natural to human language [1].

3.2 Applications of fuzzy logic in production engineering

[15] highlights the use of fuzzy logic in the areas of productive system simulation, inventory control, evaluation, optimization, decision making, control, diagnosis and information. [4] shows the application of fuzzy logic in expert systems, process identification and control, robotics, partially open systems modeling and decision pattern recognition. [6] highlights the application of fuzzy models in mean-time-between-failure (MTBF) reduction and mean-to-repair (MTTR) improvement within companies that have used these systems.

In his dissertation [5] brings some studies made using fuzzy logic applied to the area of logistic processes as the article by [20] who made an article with application of fuzzy logic for supplier selection. [18] write an article presenting a multi-criteria decision-making approach to supplier selection problems. [7] in his paper presents performance measurement through fuzzy logic within a manufacturing company's supply

chain for decision making using MATLAB.

3.3 Concept of fuzzy logic

The expression that denotes fuzzy logic can be represented by:

$$A = \{x, \mu_a(x) \mid x \in X\}$$

Where $\mu_a(x)$ is the membership function of x in A . Where $x \in X$ and $0 \leq \mu_a(x) \leq 1$. If $\mu_a(x) = 0$ represents no relevance and $\mu_a(x) = 1$ represents total relevance.

The fuzzy logic is characterized by the use of the membership function, where unlike the usual logic (crisp) that a feature belongs (1) or does not belong (0) to an element, how much approximately element x_1 belongs to A :

$$A = \{(x, \mu_a(x)) \mid x \in A, \mu_a(x) \in [0,1]\}$$

That is, in fuzzy classification the higher the value assigned to $\mu_a(x)$, the greater the relevance to A . The relevance function within fuzzy logic represents the expert's perception reflecting the technical knowledge in the analyzed subject [5]. The relevance functions can be classified into:

Triangular function

$$\text{trimf}(x; a, b, c) = \max(\min(x - a, b - a, c - x, c - b), 0)$$



Figure 1-Triangular Function.

Source: Author

Trapezoidal function

$$\text{trapmf}(x; a, b, c, d) = \max(\min(x - a, b - a, 1, d - x, d - c), 0)$$

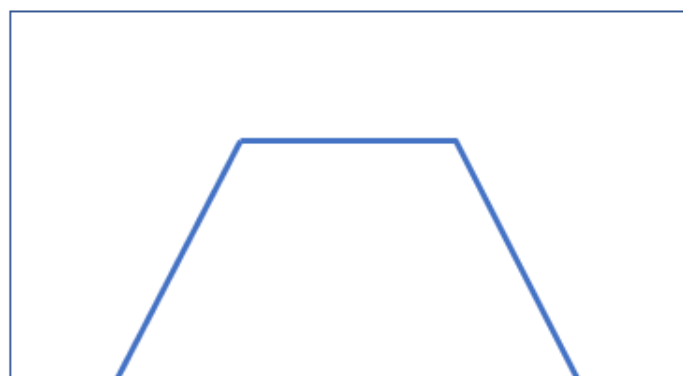


Figure 2- Trapezoidal Function.

Source: Author

Gaussian Function

$$gaussmf(x; a, b, c) = e^{-1/2(x-c)^2}$$



Figure 3- Gaussian Function.

Source: Author

Generalized Bell Function

$$gbellmf(x; a, b, c) = 1 / (1 + |x - c|^b)$$

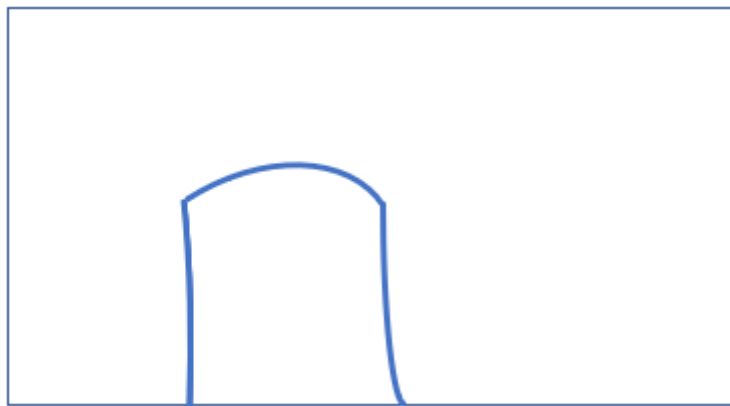


Figure 4- Bell Function. Source: Author

Fuzzy sets can have discrete expressions with the finite universe or continuous with the infinite universe, their expressions are defined as:

Discrete Expression:

$$A = \mu_A(x_1) / x_1 + \mu_A(x_2) / x_2 + \dots + \mu_A(x_n) / x_n = \sum \mu_A(x_i) / x_i$$

Continuous Expression:

$$A = \int \mu_A(x) / x$$

4. Tools and Methods

The research method used for this work is the exploratory with quantitative approach. The survey of the techniques used to choose the location of a productive plant was made through bibliographic research in books, scientific journals, articles and dissertations. The simulations and analyzes were made using the software InFuzzy, a software developed for modeling fuzzy systems, with simple interface and easy to handle and having its main functionalities related to definitions of input and output variables, rule blocks, linguistic terms and simulations. Manaus airport was chosen because most of the electro-electronic companies, according to research by [13], use this mode to transport their inputs and products.

5. Application of the study

Through bibliographic search and search sites were collected distance data between the main airport of the city of Manaus and the value of the square meter of land within the city, its surroundings and a city within the metropolitan area of Manaus.

The application began by establishing the input variables, the rule block and the output variables, as shown below.

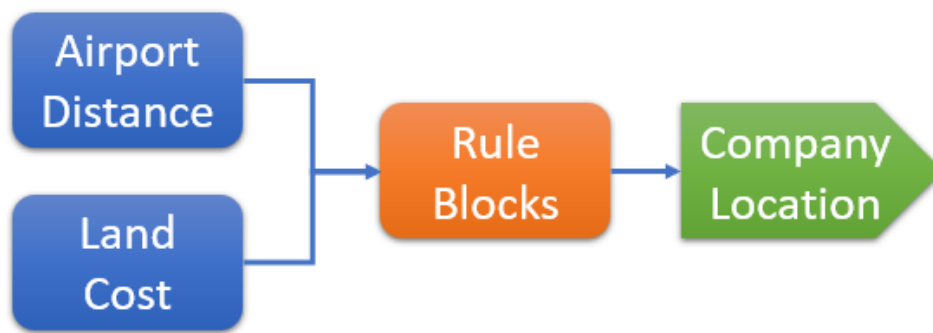


Figure 5- Relationship between input variables, rule blocks, and output variable.

Source: Author

Next, the input variable Distance from the Airport was set in a universe set from 5 kilometers to 70 kilometers from the starting point that was chosen, being as the international airport of Manaus and the linguistic variables.

Next, the input variable Cost of Land with universe of 5 to 1800 reais per square meter was set, data collected from the Manaus City Hall website. The next step was the establishment of correlation rules between the antecedent (if) and consequent (then) variables with AND connective (AND) variables. The table below shows the correlation between terms.

Table 1-Table of relationship of rules. Source: Author

N°	if	Background		then	Consequent
		Airport Distance	Land Cost		Location

1	if	Very far	expensive	then	terrible
2	if	Very far	Medium	then	terrible
3	if	Very far	Cheap	then	terrible
4	if	Far	expensive	then	terrible
5	if	Far	Medium	then	bad
6	if	Far	Cheap	then	bad
7	if	Medium	expensive	then	regular
8	if	Medium	Medium	then	regular
9	if	Medium	Cheap	then	regular
10	if	Close	expensive	then	regular
11	if	Close	Medium	then	good
12	SE	Close	Cheap	then	great

Next was set the output variable Location, which had its universe set from 0 (zero) to 10 (ten) points and its linguistic terms being: bad, bad, good, great and excellent.

Then the simulation was made using the distance and land cost variables in the neighborhoods as shown in the table below. The defuzzyfication method in this simulation was the center of gravity.

Table 2- Table with distance values and land price. Source: Author

Neighborhood	Distance (Km)	Land Cost (R \$ / m2)
Distrito Ind. I	26	138,67
Tarumã	5	125,46
Tarumã Açú	10	17,13
Puraquequara	29,4	8,80
AM 010	23	5,05
BR 174	18,8	5,88
Iranduba	42	10
Distrito Ind. II	21,7	18,82
Jorge Teixeira	24,6	80,33
Av. Torquato Tapajós	11,5	306,26

The figure below illustrates the simulations table and the results.

Time in m / s	Airport departure	Land cost	Location
46	26,00	138,67	6,77
49	5,00	125,46	9,85
43	10,00	17,13	9,85
45	29,40	8,80	6,79
46	23,00	5,05	6,74
44	18,80	5,88	9,80
45	42,00	10,00	3,50
42	21,70	18,82	6,73
45	24,06	80,33	6,75
46	11,50	306,26	9,81

Figure 6- Table with simulations. Source: Author

6. Results and discussions

The following table shows the names of neighborhoods and adjacent areas of Manaus with the distance, the value of the land and the grade obtained in the simulation.

Neighborhood	Distance	Ground	Note
Distrito Ind. I	26	138,67	6,77
Tarumã	5	125,46	9,85
Tarumã Açu	10	17,13	9,85
Puraquequara	29,4	8,80	6,79
AM 010	23	5,05	6,74
BR 174	18,8	5,88	9,80
Irاندوبا	42	10	3,50
Distrito Ind. II	21,7	18,82	6,73
Jorge Teixeira	24,6	80,33	6,75
Av. Torquato Tapajós	11,5	306,26	9,81

Table 3- Table with values of the simulations.

Source: Author

Note from 9.85 that the neighborhood Tarumã and Tarumã Açu are the best location choices using only these two variables. The second best location would be Avenida Torquato Tapajós with a grade of 9.81, even with the value of the land being the largest among the values used. The results of grade 6 were scored close to each other because the distances relatively differ little, and the value of the square meter is the

differential for obtaining the grades. The result of grade 3.5 was obtained due to the distance being much larger than the others although the value of the terrain is small.

It is then realized the usefulness of fuzzy logic as a tool for choosing a location, merit this tool for its accuracy in the results. The application of other variables could give more accuracy to the selection process and the study done by experts.

7. Final Considerations

This paper proposes to present fuzzy logic as a decision making tool through its use to create a model for locality choice. During this article it was necessary to use multidisciplinary, using mathematical and production engineering knowledge focused on the choice of location. A basic theoretical summary was presented about Fuzzy Logic, a brief history of its origins and applications.

The use of fuzzy logic as a location choice tool can be used as demonstrated by the simulations performed. With the right and most variable professionals, you can improve the use of this logic as a precision tool for decision making in companies of various sizes and segments.

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