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Implementation of a fuzzy inference system to support the evaluation of sphygmomanometers for river inspection activities in the area of legal, scientific and compliance metrology

Implementação de um sistema de inferência difusa para apoiar a avaliação de esfigmomanômetros para atividades de inspeção fluvial na área de metrologia legal, científica e de conformidade

Implementación de un sistema de inferencia difusa para apoyar la evaluación de esfigmomanómetros para actividades de inspección fluvial en el área de metrología legal, científica y de cumplimiento

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Abstract

The Amazon region has characteristics that point to logistical difficulties in meeting the demands whose inspection goal is to contribute to the economic development of the craft industry and commerce in the interior of the state, making regional products competitive, by providing technical metrological advice on procedures for verifying weighing and measuring instruments, using river vessels equipped with laboratories for testing pre-measured products, service rooms, IT and training. The Management Model for Basic River Units (UBF), aimed at carrying out inspection activities in the area of legal and scientific metrology and conformity assessment using fuzzy logic for decision-making, proposes an innovative

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management system for river units, focused on IPEM-AM's inspection activities using INMETRO's methodology. The approach uses fuzzy logic to improve decision-making, making it more accurate and efficient. The aim of the research is to evaluate a pressure device (sphygmomanometer) in order to fulfil inspection activities in the area of legal and scientific metrology and compliance, using fuzzy inference to support decision-making. The methodology used aims to improve the efficiency and effectiveness of inspection activities in these areas, reducing errors and optimising resources. Fuzzy logic is a suitable tool for dealing with the uncertainty and imprecision present in this context, allowing the system to make decisions that are closer to reality in accordance with the legislation. The results of the proposed model can be applied to different types of river units, helping to improve inspection processes and ensuring compliance with current rules and regulations. In addition, the use of fuzzy logic can provide more intelligent management that can be adapted to the changing conditions of the river environment according to the logistical purposes of the region.

Keywords: Basic River Units. Inspection. Metrology. Conformity Assessment. Logistics. Fuzzy Logic.

Resumo

A região amazônica apresenta características que apontam dificuldades logísticas para atender às demandas cuja meta de fiscalização é contribuir para o desenvolvimento econômico do artesanato e do comércio no interior do Estado, tornando os produtos regionais competitivos, fornecendo assessoria metrológica técnica sobre procedimentos de verificação de instrumentos de pesagem e medição, utilizando embarcações fluviais equipadas com laboratórios para testar produtos pré-medidos, salas de atendimento, informática e capacitação. O Modelo de Gestão de Unidades Fluviais Básicas (UBF), destinado a realizar atividades de inspeção na área de metrologia legal e científica e avaliação de conformidade utilizando lógica difusa para tomada de decisão, propõe um sistema de gestão inovador para unidades fluviais, focado nas atividades de inspeção do IPEM-AM utilizando a metodologia do INMETRO. A abordagem usa lógica difusa para melhorar a tomada de decisões, tornando-a mais precisa e eficiente. O objetivo da pesquisa é avaliar um dispositivo de pressão (esfigmomanômetro) para cumprir as atividades de inspeção na área de metrologia legal e científica e conformidade, utilizando inferência difusa para apoiar a tomada de decisões. A metodologia utilizada visa melhorar a eficiência e a eficácia das atividades de inspeção nestas áreas, reduzindo os erros e otimizando os recursos. A lógica difusa é um instrumento adequado para lidar com a incerteza e imprecisão presentes neste contexto, permitindo ao sistema tomar decisões mais próximas da realidade de acordo com a legislação. Os resultados do modelo proposto podem ser aplicados a diferentes tipos de unidades hidrográficas, contribuindo para melhorar os processos de inspeção e garantindo o cumprimento das regras e regulamentos em vigor. Além disso, o uso da lógica fuzzy pode fornecer uma gestão mais inteligente que pode ser adaptada às condições variáveis do ambiente fluvial de acordo com os objetivos logísticos da região.

Palavras-chave: Unidades Básicas Fluviais. Inspeção Metrologia. Avaliação da Conformidade. Logística. Lógica Aproximada.

Resumen

La región amazónica tiene características que apuntan a dificultades logísticas para atender las demandas cuyo objetivo de inspección es contribuir al desarrollo económico de la artesanía y el comercio en el interior del estado, haciendo competitivos los productos regionales, brindando asesoría técnica metrológica sobre procedimientos para verificar instrumentos de pesaje y medición, utilizando embarcaciones fluviales equipadas con laboratorios para probar productos premedidos, salas de servicio, TI y capacitación. El Modelo de Gestión de Unidades Fluviales Básicas (UBF), destinado a realizar actividades de inspección en el área de metrología legal y científica y evaluación de conformidad utilizando lógica difusa para la toma de decisiones, propone un innovador sistema de gestión para unidades fluviales, centrado en las actividades de inspección del IPEM-AM utilizando la metodología de INMETRO. El enfoque utiliza la lógica difusa para mejorar la toma de decisiones, haciéndola más precisa y eficiente. El objetivo de la investigación es evaluar un dispositivo de presión (esfigmomanómetro) para cumplir con las actividades de inspección en el área de metrología y cumplimiento legal y científico, utilizando inferencia difusa para apoyar la toma de decisiones. La metodología utilizada tiene como objetivo mejorar la eficiencia y eficacia de las actividades de inspección en estas áreas, reduciendo los errores y optimizando los recursos. La lógica difusa es una herramienta adecuada para hacer frente a la incertidumbre e imprecisión presentes en este contexto, permitiendo al sistema tomar decisiones que se acercan a la realidad de acuerdo con la legislación. Los resultados del modelo propuesto se pueden aplicar a diferentes tipos de unidades fluviales, ayudando a mejorar los procesos de inspección y garantizando el cumplimiento de las normas y reglamentos vigentes. Además, el uso de la lógica difusa puede proporcionar una gestión más inteligente que se puede adaptar a las condiciones cambiantes del entorno fluvial de acuerdo con los fines logísticos de la región.

Palabras clave: Unidades Básicas Fluviales. Inspección. Metrología. Evaluación de la Conformidad. Logística. Lógica Difusa.

Introduction

At the outset, it is important to note that IPEM/AM is present in 62 municipalities in the state of Amazonas, carrying out its delegated activities. The decision to use two Basic River Inspection Units (UBFFs) is based on Technical and Administrative Cooperation Agreement No. 13/2020, signed between the National Institute of Metrology, Quality and Technology (INMETRO) and the Institute of Weights and Measures of the State of Amazonas (IPEM/AM), with the intervention of the State Secretariat for Planning, Development, Science, Technology and Innovation (SEPLAN-CTI). This measure aims to strengthen the metrological public machine, through the UBFFs, ensuring that state action results in effective benefits for the population of Amazonas. This gives IPEM/AM greater capacity to move its technicians around the interior of the state, contributing to the fulfilment of the Work Plan established with INMETRO.

The success of IPEM-AM's activities depends on understanding the specific spatial and temporal circumstances of the Amazon region. As is widely known, Brazil's largest state has extremely complex transport logistics, which requires public policies tailored to its peculiarities, which makes the research whose proposed model is innovative and has no literary reference on the subject within the Amazon region, Brazil and South America with this management model to achieve these metrics according to standards established by an official body such as INMETRO. The uniqueness of the Amazon region can be seen in the difficulty of access to the various municipalities in the interior, where two out of every three towns in the state of Amazonas do not have road access. In this scenario, the citizens of Amazonas who live far from the capital and the few minimally structured municipalities access the services delegated by INMETRO through the Basic River Inspection Units (UBFFs), guaranteeing stability in commercial relations and in the economy of the interior of the state.

Therefore, as veins and arteries are essential to the human circulatory system, transporting nutrients and oxygen to the tissues, the Amazonian rivers act as access routes to most of the cities in the interior of the state and communities in the region, making it possible to transport people and goods across this vast country. This makes it necessary to contribute to and innovate the research by applying fuzzy inference to support decision-making.

Literature Review

In this context, and with a view to the common good, the structuring of the UBFFs has made it possible to strengthen relations with support organisations, and with the riverside and inland population of the state of Amazonas, through the metrological activity and conformity assessment developed by this metrological body, which are essential to protecting citizens in their consumer relations, by ensuring that the measurements used in commercial transactions are in accordance with Brazilian metrological legislation, and that products and services meet the conformity requirements assessed in INMETRO's technical regulations. This means bringing citizenship to the riverside and inland population of the state of Amazonas.

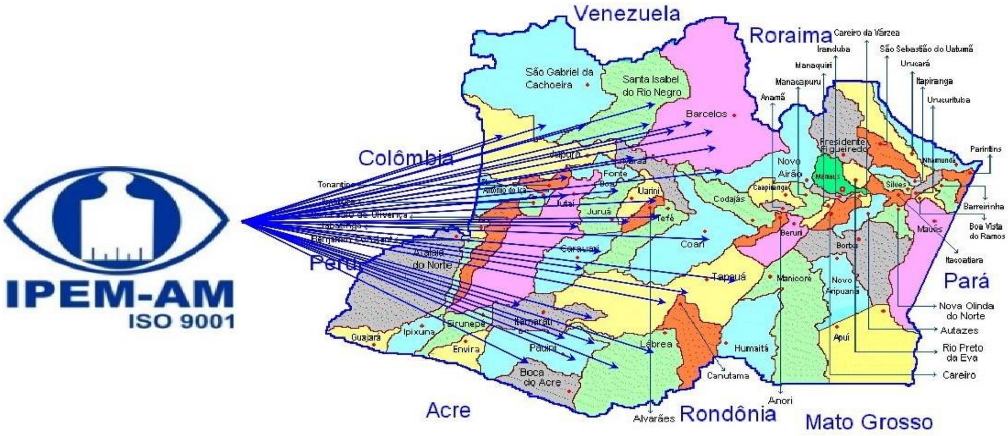
In addition, the UBFFs provide relevant support for the work and activities carried out by this INMETRO delegated metrological body, thus enabling all 61 municipalities in the interior of the state of Amazonas to be assisted more frequently, as well as enabling IPEM-AM to provide metrological coverage of approximately 55,000 km (Fifty-five thousand kilometres) of river roads, making it possible to carry out its work efficiently, effectively and efficiently.

2.1 Relevant Legislation - Feasibility Assessment

First of all, it should be clarified that IPEM/AM has the capillarity and peculiarities of being present in the 62 municipalities of the state of Amazonas, working on its scope of delegated activities, within a plan that currently includes land support for 14 municipalities, and mainly river support for the other 48 municipalities, since the Amazonian rivers are favourable to navigation, due to their volumes and extensions of water that flow in such a way as to contribute to river navigation. This makes the rivers an important means of transport for the region's inhabitants and an integral part of the lives of the inhabitants of this region of Brazil, as shown in Figure 1.

Figure 1

Map of the state of Amazonas with IPEM-AM's activities



Source: IPEM-AM, (2023).

Waterway transport is practically the only transport alternative (Figure 2), given that the roads are very limited and those that do exist do not allow transit, such as the trans-Amazonian road.

Figure 2

IPEM-AM waterway transport

The flow of IPEM/AM activities, through the support offered by the Basic River Inspection Units (UBFFs), helps to strengthen citizenship in the interior of the state by offering actions that respect and guarantee transparency in the consumer relationship between citizens, commerce and industry in general, as well as contributing to the role of the state and public policies in the spatial planning of the economy and stimulating regional development through Research and Development (RD&I) in the areas of aquatic ecosystems and flora and fauna, thus mitigating regional inequalities (Figure 3).

Figure 3

IPEM-AM waterway transport

2.2 The Management Model for Decision-Making

The ability to make decisions is essential for a company to perform well. Selecting the most suitable alternative is fundamental to achieving success (Hlavatý, Jozef; Ližbetin, Ján., 2021;Albahri, O. S. et al., 2023; Alkaraan, Fadi et al., 2023). The question then arises: what factors should be considered at this point?

The choice can be made according to intuition or based on facts. However, it is recommended to integrate these two elements. There are three methods for selecting the best alternative in this regard:

a) intuitive analysis: Decisions are made based on a hunch or intuition, without fully analysing the necessary data - this is intuitive analysis. This practice can be dangerous and cause great damage to the company (Dos Reis Lehnhart et al., 2009).

b) systematic analysis: involves using information and data as the basis for decisions. To achieve this, it is necessary to obtain as much information as possible. This approach enables a logical and ordered analysis to determine the best course of action. If the analysis appears to be wrong, it is recommended to continue looking for the most viable alternative to ensure that all the results make sense (Jankowski, Piotr. 1995; Bonczek, Robert H.; Holsapple, Clyde W.; Whinston, Andrew B. 2014);

c) decision based on principles: this method is not widely adopted, as it is based on personal principles and beliefs. The problem with this methodology is that it can lead to unethical results. It is therefore crucial to select and communicate the principles clearly, applying them to the current situation. Choices can also vary according to market changes and leadership styles (Parmigiani, Giovanni; Inoue, Lurdes, 2009).

Considering whether you will take control of this process or allow other people to influence it is crucial. As CEO, your main focus is on strategy, while the lower levels of the organisation deal with more operational choices, which can also have an impact on the company's results.

This is due to the presence of uncertainties and risks when deciding on the best course of action. In this sense, it is essential to have a well-developed strategy, as it keeps everyone aligned and reduces threats to the company (Sodhi et. al, 2012; Hopkin, Paul. 2018; Godfrey, Paul C. et al., 2020).

2.3 Logistics

Logistics is the process of efficiently planning, executing and controlling the flow and storage of products, as well as associated services and information, from the point of origin to the point of consumption, with the aim of meeting customer requirements (Pfohl, H. Chr. 2010; Ghiani, Gianpaolo; Laporte, Gilbert; Musmanno, Roberto. 2013; Winkelhaus et al., 2020). Two important characteristics of its applications are the optimisation of resources and the integration of different areas of the company:

1. Resource optimisation: Logistics seeks to maximise efficiency in the use of resources such as transport, storage, personnel and time. This involves finding the right balance between cost and service, ensuring that the company delivers its products quickly and economically (Hiddleston, Clark, 2021);

2. Integration of different areas: Logistics involves coordinating various activities and areas of the company, such as production, purchasing, distribution and customer service. An effective application of logistics requires strong integration between these areas, ensuring that they all work together to meet market demands (Hiddleston, Clark, 2021).

Transport logistics plays a key role in the supply chain, ensuring that products reach their final destination efficiently and on time. It involves coordinating different activities, such as collecting the goods, loading them onto vehicles, transporting them and delivering them to the customer. Effective management in this area can reduce costs, improve service quality and increase customer satisfaction (Rodrigue, Jean-Paul. 2012; Frazelle, Edward, 2021; Niranjan, K. et al., 2022).

River transport logistics has several distinct characteristics that differentiate it from other modes, such as road, rail, air and sea. Some of the main characteristics include (Telmer, Kevin et al. , 2006; Perrupato, Marcelo, 2009; Schilk, Gerhard; Seemann, Lukas, 2012; Divieso et al., 2021; Maciel Salazar, Guilherme Kemeron et al., 2021; Borella, Daniela Roberta et al., 2022):

1. Low cost: River transport is generally more economical than other modes, especially for the transport of bulk cargo, due to the ability to transport large volumes of cargo at once.

2. Load Capacity: River boats and vessels have a large load capacity, which makes them ideal for transporting heavy and bulky goods.

3. Environmental sustainability: Compared to other modes, river transport is more environmentally friendly as it emits fewer pollutants per tonne of cargo transported.

4. Regularity and Reliability: Rivers tend to have a fixed route, which makes river transport more predictable and regular in terms of timetables and routes, compared to other modes subject to congestion and delays.

5. Integration with other modes: River transport is often integrated with other modes, such as rail and road, through intermodal terminals, providing greater flexibility and efficiency in the logistics chain.

6. Limited infrastructure: Despite its advantages, river transport can be limited in regions where rivers are not navigable all year round or where river infrastructure is underdeveloped.

These characteristics make river transport an attractive option for companies looking for an economical, efficient and environmentally sustainable logistics solution.

2.4 Fuzzy Logic

Fuzzy logic is an extension of traditional Boolean logic that allows one to deal with uncertainty and inaccuracy more naturally. While in classical Boolean logic a value can be either true (1) or false (0), in Fuzzy logic a value can continuously vary between true and false, representing the degree of membership of an element to a set.

2.4.1 Concepts of fuzzy logic

Fuzzy logic, or multi-valued logic, was first presented in 1930 by Jan Lukasiewicz, a Polish philosopher and logician. Whilst investigating terms such as tall, old and hot, Lukasiewicz suggested using a range of values [0,1] to indicate the possibility of a statement being true or false. In 1937, Max Black, also a philosopher, proposed the idea that continuity describes degrees. He established the first fuzzy set and discussed some basic notions of operations with fuzzy sets. In 1965, Lofti Zadeh published the article Fuzzy Sets, considered to be the origin of Fuzzy Logic. Zadeh rediscovered the idea of fuzzyfication, identified and explored this concept and actively defended it. Zadeh is therefore recognised as the "master" of Fuzzy Logic (Alessandro Assi Marro, 2013; Ricardo Tanscheit, 2012; L.A. Zadeh, 1965).

2.4.2 Key concepts

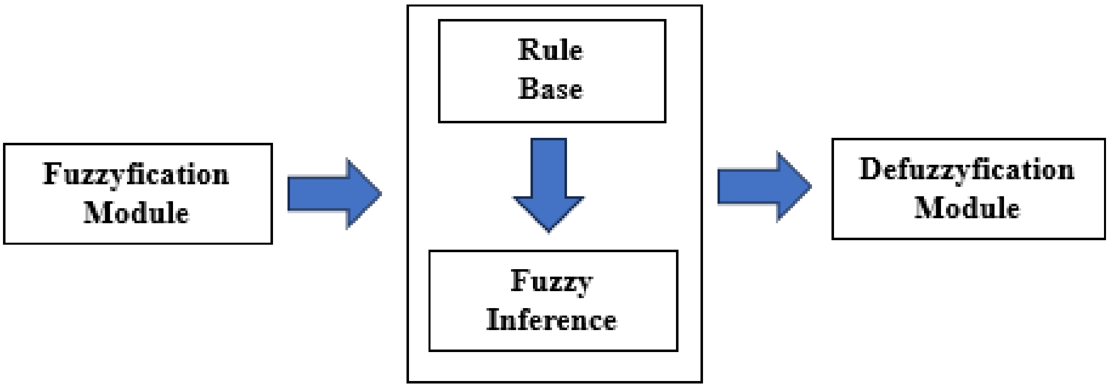
1. Fuzzy sets: sets that allow an element to belong to the set in different degrees. For example, the set "high" can include elements that are high to different degrees, such as "very high", "moderately high", etc. (Kabir, Sohag; Papadopoulos, Yiannis. Bai, Ying; Wang, Dali. 2006);
2. Linguistic Variables: These are variables that are described by linguistic terms, such as "low", "medium" and "high", rather than precise numerical values;
3. Fuzzy Rules: These are rules that describe the behaviour of a fuzzy system. For example, "if the temperature is high, then reduce the power to the heater";
4. Fuzzy Inference: The process of applying fuzzy rules to obtain fuzzy conclusions from fuzzy inputs, and;
5. Defuzzification: The process of converting a fuzzy conclusion into a precise numerical value.

2.4.3 Mathematical models

Fuzzy logic reasoning (Figure 4) follows three distinct stages, all of which are used to develop reasoning and solutions to various problems. According to the author, these stages are: fuzzyfication, inference and defuzzyfication (Peckol, 2021; Sabri, Nasseer et al., 2013).

Figure 4

Fuzzyfication and Defuzzyfication System



Source: Barros and Bassanezi (2010).

The Fuzzyficator is responsible for defining the set of fuzzy input variables that will be used in the fuzzyfication system. Fuzzy logic rules can take on values in unspecified ranges, varying, for example, between 0 and 1. This makes the range of results more precise, because even if the input data is not absolute, when defuzzyfication is carried out, an accurate result is obtained (Thaker, Shaily; Nagori, Viral.2018; Salmi, Khalid; Magrez, Hamid; Ziyyat, Abdelhak., 2019);.

In the initial phase, called fuzzyfication, the data to be processed is stored in a rule base. The antecedent and consequent linguistic variables are represented by sets. The variables are inserted into the condition rules, antecedent (IF) and consequent (THEN), generating outputs for each condition established (Kumar, Priyan Malarvizhi et al., 2018). At this stage, the degree of pertinence of each input to each fuzzy set is determined. Each of these inputs is previously defined within the universe of discourse in question and associated with a degree of pertinence in each fuzzy set based on the expert's knowledge. Thus, to obtain the degree of pertinence of a given crisp input, simply look up this value in the fuzzy system's knowledge base (Mendel, Jerry M., 1995).

2.4.4 Relevance functions in fuzzy logic

According to Do Carmo Corrêa & Da Silveira, A. M. (2012), in Fuzzy Logic, the pertinence of an attribute depends on the perception and experience of the expert on the subject in question. These pertinence functions can be demonstrated in various ways, the most common being classified as:

2.4.4.1 Triangular function

The triangular function requires 3 points (x, y, z). These values must fulfil the a<b<c rule. There must be some value where the pertinence is 1. Eq. (1) is used to represent the triangular function (Figure 5a):

$$trimf\ (x; a, b, c) = \max(min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0) \qquad (1)$$

2.4.4.2 Gaussian function

The Gaussian pertinence construction uses three parameters: x, mean and standard deviation. Figure 5c shows the Gaussian pertinence function and Eq. (2) illustrates the Gaussian function:

$$gaussmf(x, a, b, c) = \ e^{-\frac{1}{2}(\frac{x-c}{\sigma})^2} \qquad (2)$$

2.4.4.3 Trapezoidal function

The trapezoidal pertinence function is represented by Eq. (3), where the points of obey the rule a. An interesting feature of this function is that it allows a pertinence interval of 100%. Figure 5b shows this function.

$$trapmf\ (x, a, b, c, d) = \max(\min(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}, 0) \qquad (3)$$

The functions are represented graphically in Figure 5:

Figure 5

Examples of pertinence functions

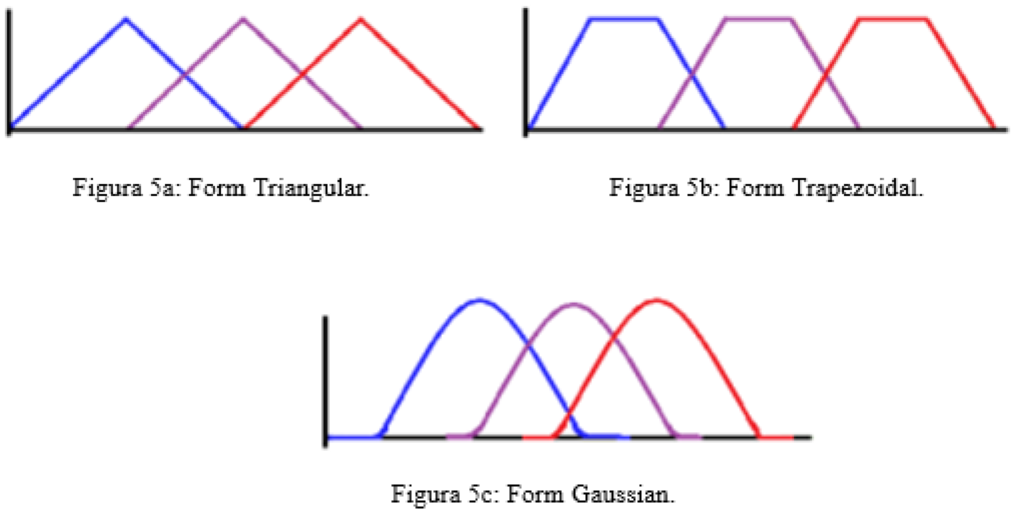


Figura 5a: Form Triangular.

Figura 5b: Form Trapezoidal.

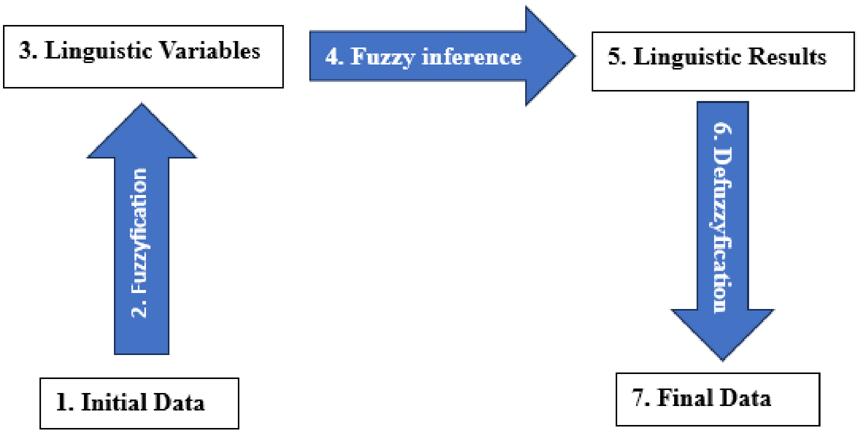
Figura 5c: Form Gaussian.

Source: Yildiz (2010).

The Fuzzy Logic System is structured in three steps, as shown in Figure 6, adapted from Santos, P. V. S.; Araújo, M. A. (2018). In the first step, there is "fuzzyfication" (2), in which the initial data (1) is transformed into linguistic variables (3), a phase in which all information relating to the imprecision or uncertainty associated with these variables must be taken into account. In the second step, once the initial values have been transformed into linguistic variables (3), fuzzy "inference" is the next phase (4), the aim of which is to compare the probable variables with each other using pre-established standards, with the objectives of the algorithm having been achieved.

Figure 6

Fuzzy Logic System



Source: Santos, P. V. S.; Araújo, M. A. (2018).

Materials and Methods

3.1 Methodology of Direct and Indirect Benefits

The use of the Basic River Inspection Units (UBFFs) will meet the needs of the full operation of metrological activities and conformity assessment of products, processes and services, as well as providing peace of mind and support for metrological control services, thus enabling the prevention, guarantee and verification of compliance with regulatory requirements by measuring instruments.

As an agile and modern structure to help carry out integrated activities and control, the Basic River Inspection Units (UBFFs) in the area of Quality will also provide the peace of mind and support needed to verify the degree of compliance (or conformity) of a product, process or service with the minimum requirements established in standards or technical regulations.

The flow of IPEM/AM activities and the support offered by the UBFFs helps to strengthen citizenship by offering action that respects and guarantees transparency in the consumer relationship between citizens, commerce and industry in general, as well as Research and Development (RD&I) in the areas of aquatic ecosystems and flora and fauna, thus mitigating regional inequalities. In addition, this flow of activity and support from the UBFFs is developed in a planned way by river channel and the municipalities they cover, as described in Figure 7:

3.2 Procedures (Steps) Used

Figure 7

River channels x municipalities

	River channels	Municipalities
3.2.1	Madeira River channel	Municipalities (6): Apuí (BR 230_Rodovia Transamazônica), Borba, Humaitá, Manicoré, Nova Olinda do Norte and Novo Aripuanã.
3.2.2	Purus River channel	Municipalities (7): Beruri, Boca do Acre, Canutama, Lábrea, Pauini e Tapauá.
3.2.3	Amazon River Channel (Lower Amazon Region)	Municipalities (8): Barreirinha (Rio Curuçá, Afluente do Rio Amazonas), Boa Vista do Ramos (Rio Curuçá, Afluente do Rio Amazonas), Maués (Rio Maués-Açú, Afluente do Rio Amazonas), Nhamundá (Rio Nhamundá, Afluente do Rio Amazonas), Parintins, São Sebastião do Uatumã (Rio Uatumã, Afluente do Rio Amazonas), Urucará (Rio Uatumã, Afluente do Rio Amazonas) e Urucurituba.
3.2.4	Solimões River channel	Municipalities (27): Alvarães, Amaturá, Anamã, Anori, Atalaia do Norte (Rio Javari, Afluente do Rio Solimões), Benjamin Constant, Caapiranga (Rio Macurani, Afluente do Rio Solimões), Carauari (Rio Juruá, Afluente do Rio Solimões), Coari, Codajás, Eirunepé (Rio Juruá, Afluente do Rio Solimões), Envira (Rio Tarauacá-Rio Juruá, Afluente do Rio Solimões), Fonte Boa, Guajará (Rio Juruá, Afluente do Rio Solimões), Ipixuna (Rio Juruá, Afluente do Rio Solimões), Itamarati (Rio Juruá, Afluente do Rio Solimões), Japurá (Rio Japurá, Afluente do Rio Solimões), Juruá(Rio Juruá, Afluente do Rio Solimões), Jutaí, Manacapuru, Maraã (Rio Japurá, Afluente do Rio Solimões), Santo Antônio do Içá (Rio Iça, Afluente do Rio Solimões), São Paulo de Olivença, Tabatinga, Tefé (Rio Tefé, Afluente do Rio Solimões),Tonantins e Uarini.
3.2.5	Amazon River Channel (Metropolitan Region and Rio Negro)	Municipalities (14): Autazes, Barcelos (Rio Negro), Careiro, Careiro da Várzea, Iranduba, Itacoatiara, Itapiranga, Manaquiri, Novo Airão, Presidente Figueiredo, Rio Preto da Eva, Santa Isabel do Rio Negro (Rio Negro), São Gabriel da Cachoeira (RioNegro) e Silves.

3.3 Social Impact Procedures (Stages)

The IPEM-AM's presence brings citizenship and information to hundreds of riverside dwellers and Amazonians who are denied part of their citizenship. It's worth noting that simple, everyday activities in Brazil's major metropolises have been taken to the interior of the state, such as inspections of land and river petrol stations (pontões), scales at local markets and butchers, restoring fair and dignified trade in these locations, as shown in Figure 8.

Figure 8

Localities in the interior of the state of Amazonas

The UBFFs have service, IT and training rooms, as well as metrological testing laboratories, for carrying out their delegated activity, and means of contributing to the social inclusion of the riverside and inland population, in the sense of fully bringing the right to citizenship to the population in the interior of the state, which is a challenge faced by IPEM-AM's employees and professional partners in order to mitigate the differences (Figure 9).

Figure 9

Procedures in the interior of the state of Amazonas

One example is the assistance provided in issuing identification documents, in partnership with institutions of the Amazonas State Government (Figure 10).

Figure 10

Local harbour in the interior of the state of Amazonas

3.3.1 Collection Procedures (Stages)

The evidence shown above demonstrates the social impact of the use of the UBFFs on riverside communities and communities in the interior of the state. For this reason alone, the realisation of this project is justified, as it makes the unequal more equal through the provision of services by the Federal Government, through INMETRO, in the Amazon region. Having said that, we must emphasise that this project also plays a fundamental role in the growth of the targets set in the Work Plan. With an increase in the order of 11,000 weighing and measuring instruments in the interior of the state, we can expect a result of more than 10% of the total collected in the year by this delegated body.

3.4 Fuzzy Logic Procedures

Step 1: defining the management model based on fuzzy logic for decision-making can be described as follows:

Stage 2: stating the idea of the decision-making problem, including the variables involved and their relationships.

Step 3: identify the variables relevant to the decision and define fuzzy sets for each variable to represent the linguistic terms (e.g. Bad, Average and High).

Step 4: design membership functions to map the fuzzy sets to the real values of the variables, indicating the degree of membership for each set.

Step 5: Rule Base - develop a rule base that defines the logical relationships between the input variables and the output.

Step 6: Fuzzy Inference System - the defined fuzzy sets, membership functions and rule base were used to create a fuzzy inference system that processes the input variables to produce a fuzzy output.

Step 7: Defuzzification: the fuzzy output was converted into a clear value using defuzzification methods such as the centroid or the average of the maxima.

Step 8: Decision-making: based on the defuzzified output, make a decision or take action according to a criterion predefined in the rules.

Step 9: Feedback and adjustment: to continuously monitor the results of the decision and adjust the model's parameters or rules if necessary to improve performance.

This model allows imprecise or uncertain information to be dealt with in decision-making processes, making it particularly useful for complex systems where traditional logic may be insufficient to evaluate the linguistic variables: Pressure Value Display (PVD), Graduation Mark Display (GMD), Errors Traced (ET) and Quality of Display Identification (QIM).

3.5 Methodological Evaluation Process

The Methodological Process was divided into three distinct stages: 1. Identification of the indicators for Display of Pressure Values (EVP), Display of Graduation Marks (EMG), Traced Errors (ET) and Quality of Display Identification (QIM) verified in Item of Ordinance No. 341, of 9 August 2021 approving the consolidated Metrological Technical Regulation for non-invasive measuring sphygmomanometers (INMETRO, 2021), Item 3 (Technical Resources, sub-items: 3. 7.1, 3.7.3 - II and III and 3.7.5 - II); 2. Modelling of the Fuzzy Inference System; 3. Experimentation of the Proposed Model, with the following phases: Phase 1 (definition of the inference levels of the indicators), Phase 2 (Development of the Fuzzy Sets, Development of the Inference Rules and Simulation in the MatlabR2013 software), Phase 3 (Compilation of the Indicator Aggregation Algorithm, Simulation of the Results in 3D and Analysis of the Results Obtained).

Figure 11

Shows the Methodological Process

PHASES OF THE FUZZY PROCESS	STEPS
1. Identification of Indicators (Linguistic Variables)	1.1 Definition of the indicators' Levels of Inference
	2.1 Development of the Fuzzy Set

2. Modelling the "Fuzzy Inference" System	2.2 Development of the Inference Rules 2.3 Matlab R2013a software simulation
3. Testing the Proposed Model	3.1 Compilation of the Indicator Aggregation Algorithm 3.2 Simulating the Results in 3D 3.3 Results obtained

Phase 1 consisted of identifying the indicators (EVP), (EMG), (ET) and (QIM) (INMETRO, 2021) for the evaluation of the sphygmomanometer device to be evaluated, which was adapted to Fuzzy Logic in its result for analysis. The aim of this stage is to identify the potential performance of the evaluation, to assess whether it has good operational results and pass and/or fail rates, or whether the results are irregular in general terms for decision-making.

Phase 2: MatLab R2013a - Fuzzy Toolbox Student version software is used to specify the input and output variables, with their respective rangers, types of relevance function and their respective linguistic levels.

Stage 3 compiles the results obtained for the final definition of the simulation'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.

The experiment produced 81 performance rules, individually assessed by technical criteria, with the aim of supporting decision-making in the industry and ensuring that it is highly trained, thereby increasing product performance and optimising costs.

The reason for choosing the indicators is that they address several important points in UBFF inspection, such as Pressure Value Display (PVD) - the pressure value must be displayed directly, clearly and unambiguously, without the need to use a multiplication or conversion factor, Graduation Mark Display (GRD) - the graduation marks must be clear, well delineated and of uniform distance and thickness, Tracing Errors (TE) - tracing errors must not be easily perceptible and the thickness of the marks must not exceed 1/5 of the distance between two consecutive marks, with uniform distance and thickness, Tracing Errors (TE) - tracing errors must not be easily perceptible and the thickness of the marks must not exceed 1/5 of the distance between two consecutive marks on the scale, Quality of Display Identification (QIM) - where all display indications must be identified in Figure 12.

Figure 12

Processo de Avaliação

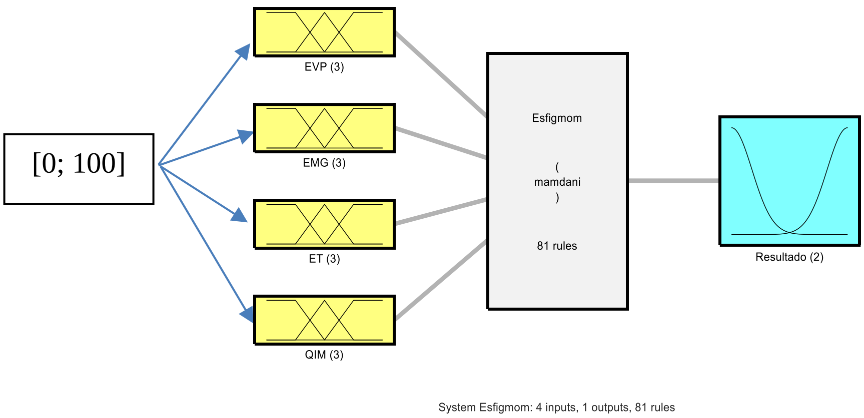
INDICADORES	ITENS DE AVALIAÇÃO	MÉTRICAS
Visualisation of the	The pressure values must be displayed directly, clearly	Fair: 25 to 75

Pressure Values (PVS)	and unambiguously, without the need for multiplication or conversion factors.	Bad: 0 to 50 Good: 50 to 100
Graduation Marks Display (EMG)	Graduation marks must be clear, well delineated and of uniform distance and thickness.	Fair: 25 to 75 Bad: 0 to 50 Good: 50 to 100
Plotted Errors (TE)	Low, Medium and High	Fair: 25 to 75 Bad: 0 to 50 Good: 50 to 100
Quality of Display Identification (QIM)	All display indications must be labelled and clearly legible.	Fair: 25 to 75 Bad: 0 to 50 Good: 50 to 100
Results Achieved	The Gaussian output variable with a range of 0 - 1.	Fail: 0 - 0.5 Pass: 0.5 - 1.

Figure 13 shows the 4 linguistic variables (Fuzzyfication), the Base of 81 Mandani Fuzzy Rules and the Defuzzyfication (Output) as the Inference model.

Figure 13

Fuzzy inference model



The system has four inputs and one output. The four inputs have amplitudes in the range [0; 100], and the output [0; 1]. The inputs and outputs are collected based on the results analysed. Figure 13, you can visualise the specified fuzzy inference model in more detail, with its respective rangers.

Results and Discussions

Fuzzy logic inference can be applied to river transport in a number of ways, especially to deal with the imprecise and uncertain nature of many aspects of this type of transport. Here are some common applications:

a) Fuzzy logic - can be used to optimise river traffic control, taking into account factors such as weather conditions, traffic density, water depth and vessel capacity. The fuzzy system can help make decisions about speed, route and safe distance between boats;

b) Forecasting demand for enforcement - Demand for river transport can be uncertain and vary over time. Fuzzy logic can be used to model demand patterns, taking into account factors such as the time of year, special events and economic conditions;

c) vessel maintenance - fuzzy logic can be applied to programme preventive maintenance for vessels based on factors such as time of use, operating conditions and maintenance history. This can help avoid unexpected failures and reduce maintenance costs;

d) Cargo management for the interior of the state of Amazonas - Fuzzy logic can be used to optimise cargo management on vessels, taking into account cargo characteristics, vessel capacity and operational constraints. This can help maximise transport efficiency and reduce costs;

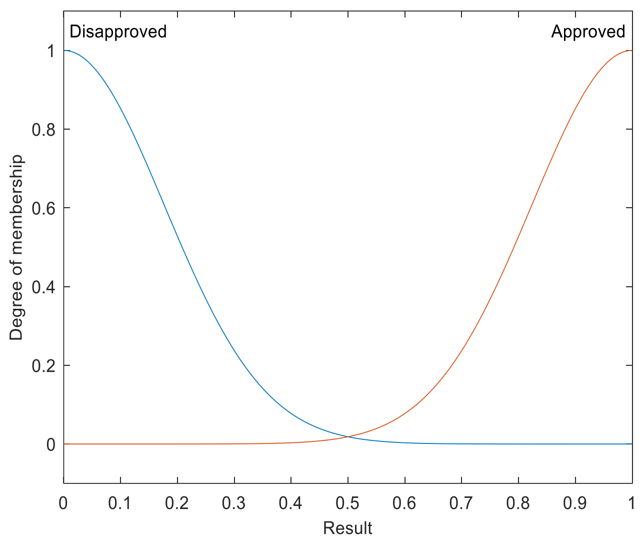
e) Navigation safety - Fuzzy logic can be applied to improve safety and navigation on rivers, taking into account factors such as visibility, currents and obstacles. Systems based on fuzzy logic can help make decisions about the speed and route of vessels to avoid collisions and groundings.

These are just a few of the many ways in which fuzzy logic can be applied to river transport to guarantee stability in the monitoring of equipment calibrated to take these measurements within the standards set by INMETRO. The ability of fuzzy logic to deal with uncertainty and imprecision makes it a powerful tool for improving the efficiency, safety and reliability of river transport and the metrics for carrying out inspections without having problems with the equipment being used properly. This being the case, it is now time to evaluate the results applied with the artificial intelligence tool using fuzzy inference.

Figure 14 shows the output results where 0 to 0.5 shows the degree of disapproval and 0.5 to 1 shows the approved result.

Figure 14

Defuzzification output results

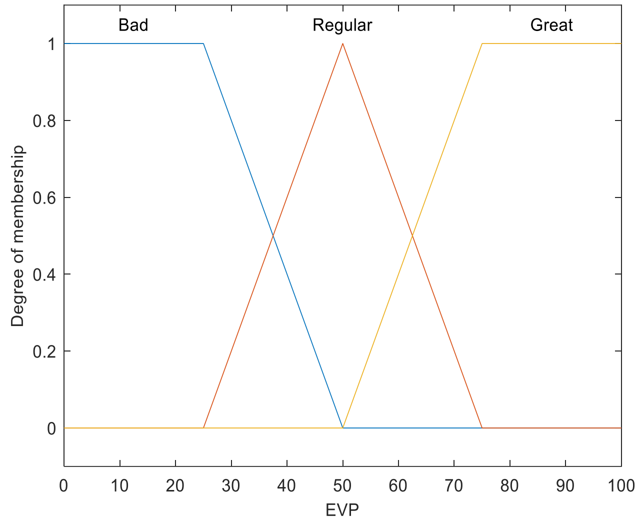


4.1 Pressure Value Display (EVP)

Figure 15 shows the pertinence function for the linguistic input variable Pressure Value Display (PVD), which is designed to directly display the pressure values in a clear and unambiguous way, without the need to use a multiplication or conversion factor (INMETRO, 2021). The results shown are the following linguistic values: Regular: 25 to 75, Bad: 0 to 50 (between 0 and 0.5 - Fail) and Optimum: 50 to 100 (between 0.5 and 1 - Pass). The indicator was based on the result of three indices that represent the reality of the equipment's evaluation: availability, performance and quality. The linguistic variable "EVP" has four levels of inference, with trapezoidal and triangular shapes.

Figure 15

Pertinence function for the EVP input variable

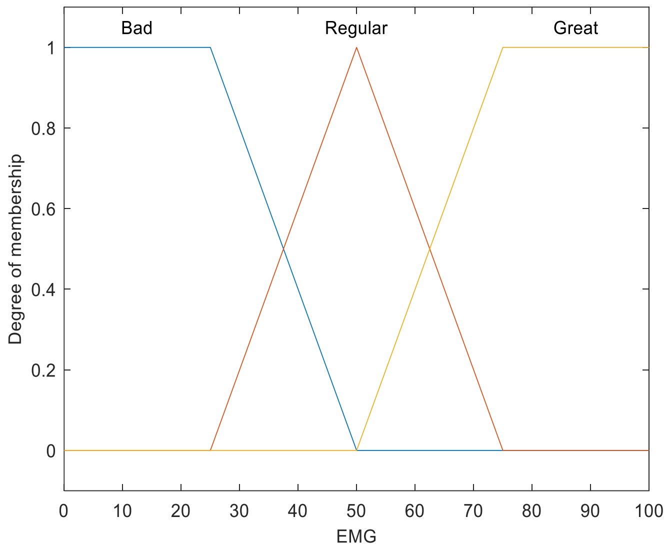


4.2 Display of Graduation Marks (EMG)

In this indicator, whose pertinence function of the EMG linguistic variable, it is possible to verify aspects such as: the graduation marks must be clear, well delineated and with uniform distance and thickness, thus the linguistic variable "EMG" (INMETRO, 2021) constitutes three levels of inference, with trapezoidal and triangular formats. Figure 16 shows the trapezoidal and triangular structures, given linguistic values: Bad (0 to 0.5), Fair (25 to 75), Great (50 to 100).

Figure 16

Degree of Relevance for the EMG input variable



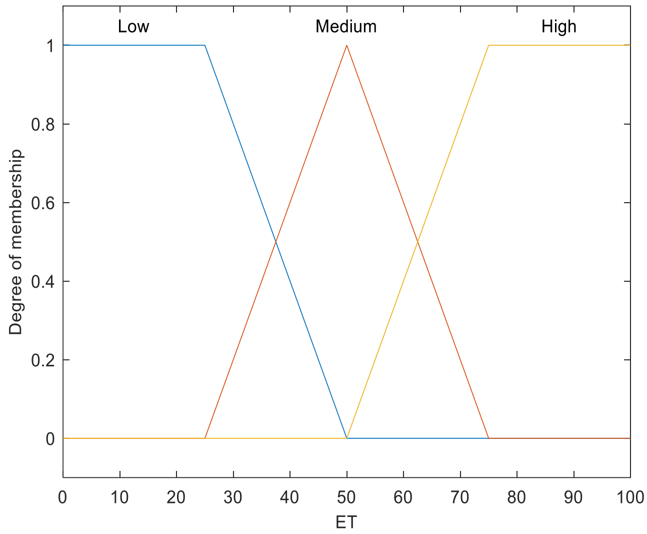
4.3 Traced Errors (ET)

Indicator showing the linguistic variable of Traced Errors (ET). Figure 17 shows the values for Bad, Fair and Good, ranging from 0 to 50, 25 to 75 and 50 to 100 respectively.

The linguistic variable "ET" has three levels of inference, with trapezoidal and triangular shapes. Figure 17 shows the trapezoidal and triangular structures, with linguistic values: Low, Medium and High.

Figure 17

Degree of Relevance for input variable ET



4.4 Quality of Display Identification (QIM)

In a direct and precise manner, the Pertinence Function indicator for the QIM input variable is the point at which the Quality of Display Identification is equal, i.e. "uniform". Where it demonstrates the ability to assess being covered, i.e.: Poor (from 0 to 50), Average (25 to 75) and High (from 50 to 100). The linguistic variable "QIM" has three levels of inference, with trapezoidal and triangular shapes. Figure 18 shows the trapezoidal and triangular structures, with linguistic values: Low, Medium and High.

Figure 18

Degree of Pertinence for input variable QIM

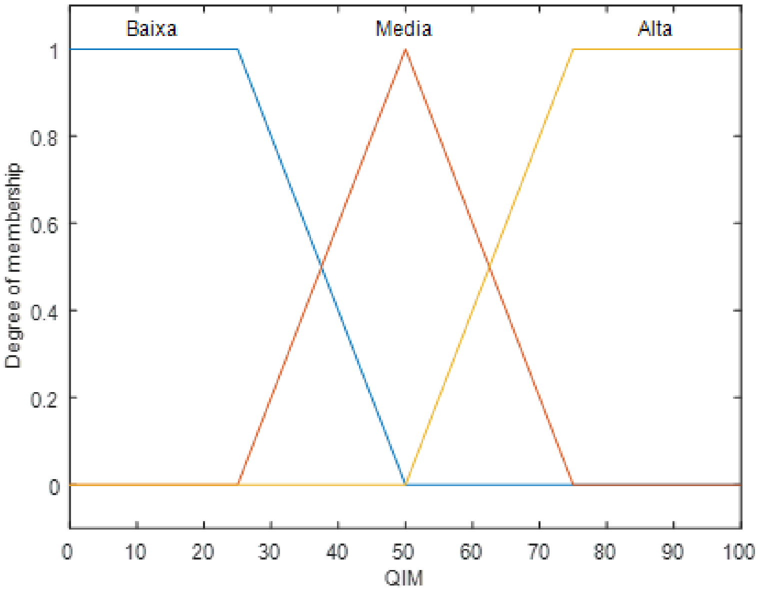
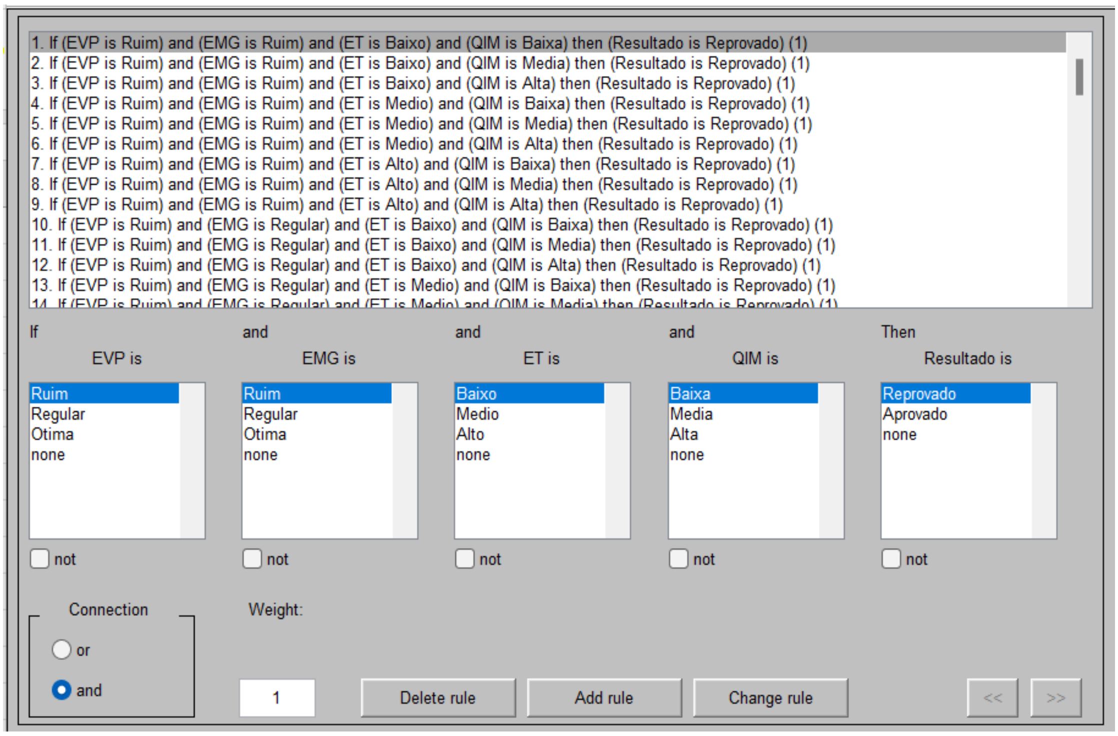


Figure 19 shows part of the 81 (eighty-one) rules established for the defuzzification system, based on the combination of input variables and their levels of inference.

Figure 19

Rules



After inserting the rules, the results are simulated, identifying the performances diagnosed with moderate inference, poor definition and optimal definition of results. These simulations offer a more complete view of the influence of each indicator on the study's output, as shown in Figure 20.

Figure 20

Simulation for Approved Result

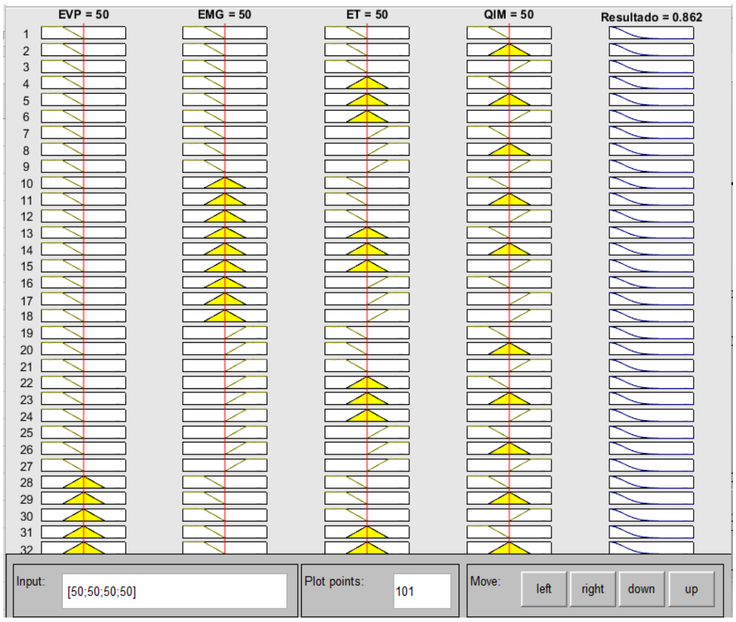
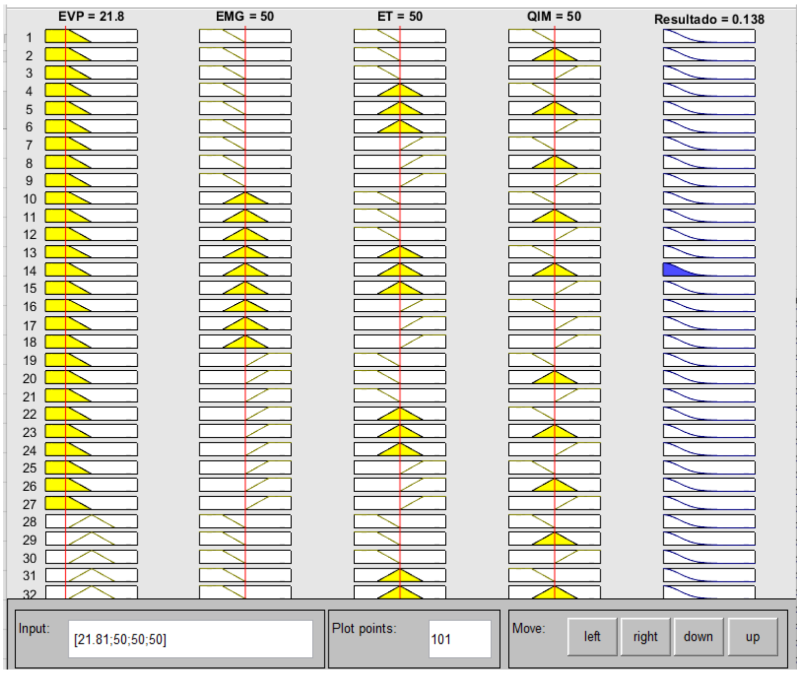


Figure 20 shows that when the EVP indicator is set to 50 (Fair), the EMG indicator is set to 50 (Fair), the ET indicator is set to 50 (Average) and finally the QIM indicator is set to 50 (Average), the evaluation result will be identified with a degree of pertinence of 0.862. Therefore, the result of the assessment of the sphygmomanometer will be Approved with 86.2%.

Figure 21

Shows the simulation for a Fail result



In Figure 21, it can be seen that when the EVP indicator is set to 21.8 (Bad), the EMG indicator is set to 50 (Fair), the ET indicator is set to 50 (Average) and finally the QIM indicator is set to 50 (Average), it has a significant impact on the result, even if the other indicators are kept as intermediate definitions. This result has a negative influence on the degree of relevance of the result by 0.138. Therefore, the result of the sphygmomanometer assessment will be Fail with 13.8%. Figure 22 shows the simulation for a Fail result with a low degree of pertinence for the QIM indicator.

Figure 22

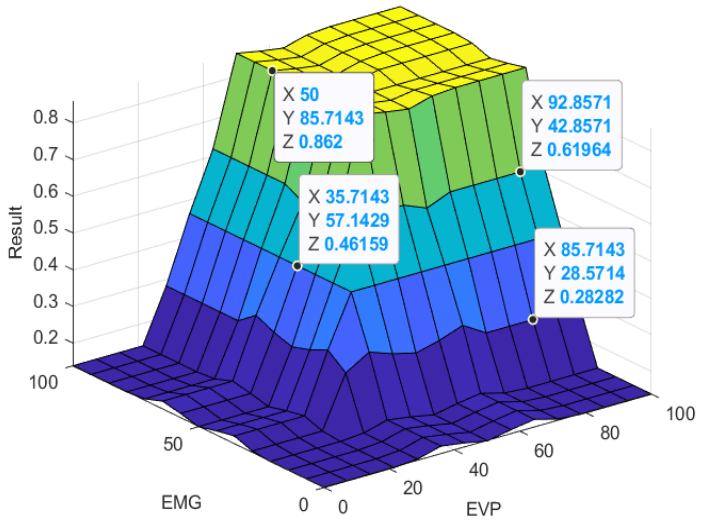
Simulation for Fail result with QIM (Low)

In Figure 22, it can be seen that when the EVP indicator is set to 78.2 (Good), the EMG indicator is set to 50 (Fair), the ET indicator is set to 50 (Average) and finally the QIM indicator is set to 17.6 (Low), it has a significant impact on the result, even though the indicators (EMG and ET) are kept at intermediate settings. This result has a negative influence on the degree of relevance of the result, with a final value of 0.138. Therefore, the result of the assessment of the sphygmomanometer will be Fail with only 13.8% relevance, in accordance with the parameters established by the Ordinance (INMETRO, 2021).

The preliminary evaluation system developed serves as support for inspection. Not only does it deal with the quality and reliability of the measurement, but it also deals with the economic benefits that the result will bring, so that it can be worked on more precisely in its method of measurement and interpretation by the most appropriate inspector, which will generate an even higher level of accuracy in interpreting the results.

Figure 23

Reflection of EVP and EMG Inputs on the Result



Step 3.2 then presents the simulation of the results in 3D, which makes it possible to observe the analysis of the behaviour of the variables, as shown in Figure 23 (3D Graph), and to adjust the fuzzy sets and the "inference" rules in order to express the characteristics presented by the experts during the modelling of the problem. It should be pointed out that this modelling presented above is of the Defuzzification Output related to the EVP, EMG, ET and QIM Inputs and that it is possible to generate other analysis modelling by varying the Inputs that were used to carry out the research.

Conclusions

The description of the EVP, EMG, ET and QIM indicators made it possible to carry out the analyses in the study. For example, if we take one of the evaluations from these analyses, specifically the evaluation of the sphygmomanometer device as shown in Figure 19 (Inference rules), considering that the EVP, EMG, ET and QIM indicators show the results of the fuzzy inference simulation, the efficiency of the sphygmomanometer evaluation can be adequately monitored to a satisfactory degree, which is regulated by the Ordinance (INMETRO, 2021), but a standard pace of equipment evaluation can be maintained due to the good results of the other indicators. After evaluating all the rules (81), the most significant variables for the research were identified. The development of the Fuzzy Inference System made it possible to aggregate the evaluation data for the sphygmomanometer indicator according to the pre-determined criteria (Fuzzyfication), establishing a computer model based on the classification rules for the evaluation of a given piece of calibrated equipment, making it possible to assess its optimisation in relation to the conformities under study. The fuzzy system was able to show the different performance results when simulated with the different conditions of the input variables and whose projected performance rating could be defined. The fuzzy system can be used to determine which evaluation method is best suited to the sphygmomanometer being worked on so that it can comply with the Ordinance (INMETRO, 2021) and improve the safety margin of the IPEM-AM/INMETRO inspection, enabling a more critical analysis in internal inspection decision-making. The experience of professionals in the IPEM-AM/INMETRO inspection area or similar areas brings even more relevance to the study project, due to the contribution that experts can make after analysing the study model. More concrete data is extracted from real situations that occur in IPEM-AM/INMETRO's internal processes. The proposed model obtained satisfactory results in analysing the performance classifications of the Sphygmomanometer evaluation in order to meet the particularities of Ordinance 341/INMETRO. Based on the data entered into the Fuzzy Logic, the model was able to generate information to improve the decision-making process, optimising the evaluation of inspection processes when using different gauged equipment. This research data shows that the level of development has been boosted to reliable levels. It is important to note that the proposed model can be analysed even by professionals with less experience, as it helps to reduce the complexity of the study when making decisions.

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