Risk Assessment Proposal in Hydraulic Presses with Fuzzy Logic

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Abstract

The aim of this study was to evaluate the safety level of industrial machines, in particular hydraulic press. The dissertation used hydraulic presses as the object of study. The research instruments used were machine safety analyzes based on normative items pre-established in ABNT NBR: 12100, possible accidents that these machineries can cause. The results show that hydraulic presses cause many accidents, in some situations dying. Through Annex B of ABNT NBR 14153: 2013, there are 4 risk categories for machinery, the greater the degree of risk, the more unsafe the machine is. The appraiser's experience is very important to analyze the machine and reach the level of risk level before and after the adjustment. Finally, it appears that the machine analyzed in this study was at risk level 3, after analysis and adaptations the same machine was at risk level 1, totally acceptable to maintain the operator's safety level.

Keywords: *industrial machines; hydraulic press; risk level; accidents; safety; ABNT NBR 14153: 2013.*

1. Introduction

Intense discussions about the health of the worker have been focused on Medicine and Safety at work, due to the significant increase in accidents mainly with industrial machinery and equipment. Amputations, lacerations and even death, have left workers insecure and psychologically shaken[25].

Inadequate work environment, unsafe act, lack of knowledge of the worker in relation to the activity to be performed, can contribute to accidents occurring. The situations can be isolated or together and in all cases the employer is directly related, since the machinery should have been adequate since 1978 when Ordinance MTb nº 3,214 was enacted, the parameters were established by Regulatory Norm NR12 - Safety in Machines and Equipment of the Ministry of Labor and Employment and has undergone several changes since then, by Ministry of Labor and Employment (2020).

Notably, accidents have a direct influence on the worker's life, and may reduce work capacity, in the event of loss of limbs or incapacitating accidents, subjecting their dependents to losing perhaps the only source of family income, and bringing social costs, mainly in Health and Social Security (JUNIOR,2009).

According to the Ministry of Social Security (2001, p. 01), the damages caused by accidents at work are of a direct, immediate order, either due to the health or physical integrity of the employee and the health of his dependents, perhaps losing the mainstay of the family. It is still necessary to comment on the costs that are generated for the state with Health and Social Security. The losses are numerous and go beyond the physical level, often emotionally affecting employees not only directly involved in the accident but their co-workers who may be shaken by the event.

In 2019, there were some changes in the parameters of verification and adequacy of machines and equipment. SEPTR Ordinance No. 916 of 07/30/19, excluded several items contained in the NR-12 - Safety at Work in Machinery and Equipment, as for example: import of machinery, in the previous wording it was necessary to adapt as soon as they were installed in the industries, significantly increasing the costs with machinery and labor to perform the service. With the modification, businessmen are released from this suitability if the machinery is already adequate with safety measures even if they are international and have a compliance report. This change brought relief to employers who can invest this amount that they would spend on adapting to other security measures within the company, or even training their technical personnel.

Despite the modifications in the NR-12 - Safety in Machinery and Equipment norms, the origin, degree of risk and severity of the damage observed in NBR 14153: 2013 are still in force (MTE, 2020).

According to the regulatory standard NR-12 - Safety in Machinery and Equipment, all equipment must be adequate so as not to cause any injury, whether temporary or permanent to the operator. This standard has an annex (ANNEX - VIII PRESSES AND SIMILAR) dedicated to this type of equipment identifying the points of attention and how to carry out the adaptation in order to satisfy the precepts of the regulatory standard and other Brazilian standards (MTE, 2020)

According to Annex VIII - Presses and Similars - NR12 (MTE, 2020), the presses are machines that have the capacity to conform, cut materials of different compositions. They consist of tools that move the “hammer” (punch) that can be driven by a hydraulic or pneumatic system, hydraulic or pneumatic cylinder, or a mechanical system. They are heavy and very powerful machinery, where their failure can cause lacerations, amputations and, in more drastic scenarios, death.

Hydraulic presses are undoubtedly one of the machines that cause the most accidents in the industries, and with the economic opening, many of these machinery coming from Asian countries or the Middle East, arrive in the country without the proper protections or safety adjustments exposing workers to the serious risks to physical and psychological integrity (JUNIOR, 2009).

An important part of these accidents is caused by obsolete, unprotected and unsafe machines, being verified by the government through inspections (STUMPF, 2005).

Injection and mechanical presses have been the biggest cause of accidents in Brazil. Within this problem, the government has concentrated efforts to understand why. In investigations, there are several reasons, such as: lack of knowledge and preparedness of entrepreneurs to apply the normative requirements in their companies, lack of awareness of people, both employees and employers, about the importance of safety with this type of machinery for the preservation of physical integrity. and psychological of its collaborators, thus making it difficult to reduce expenses with early retirements and costs in general with treatment for the injured (STUMPF, 2005).

According to Vilela (2000), several initiatives were taken to establish appropriate safety measures for workers who operate presses, due to the high risk of crushing, amputation and death.

In 2002, the “Collective Convention for the Improvement of Working Conditions in Presses and Similar Equipment, Plastic Injectors and Galvanic Treatment of Surfaces in the Metallurgical Industries in the State of São Paulo” was signed, with union leaders and workers representatives in front of them class, in order to establish minimum conditions and safety criteria for press workers. This convention had 62 workers 'unions, 11 employers' unions and as a mediator the Regional Labor Office of the State of São Paulo (DRT / SP) (MTE, 2002).

From this convention, several operations of inspection of presses and the like started through the Ministry of Labor and Employment, culminating in the elaboration of Technical Note nº 16 - DSST / MTE, serving as a reference and technical support (MTE, 2005) .

Industrial machines have been the focus of regulatory bodies for safety adequacy, as they signal high numbers of accidents as evidenced by SISLAB (2020), only the northern region holds 15% of accidents in industrial machines, and in presses this percentage represents in around 7%, a very high number considering the number of inhabitants of the region. These figures did not include death, which would significantly increase this percentage.

For the adequacy of machines, the NBR's (Brazilian Norms) have a large list of information that helps in the analysis and guides to the correct form of adequacy with safety. The use of the methodology covered in NRB 14153: 2013, for example, helps to make an analysis of the risks and dangers of the machine under study and the use of the most plausible resources for the adequacy of the machinery being studied.

The relevant factor of the presses contributing to a significant participation of accidents, motivated the question of obtaining an inference model that could more quickly and accurately diagnose, through something already defined in ABNT NBR 14153/2013, the category of the degree of risk of machine, giving a more precise direction to the technical analyst when making a decision to propose an efficient adaptation that is able to meet the pre-established normative requirements.

In this approach, the present work intends, based on the tool presented in NBR 14153: 2013, to propose a Fuzzy inference model to assist in the categorization of the degree of risk of industrial machines, seeking to subsidize improvements in safety at work with this equipment, as well as to propose suggestions that aim to improve the adaptations of machines and equipment and the analysis of accidents faster and more efficient.

2. Methodology

2.1 Fuzzification

Presses have been configured over the years; an extremely important machinery due to the types of accidents they can cause to the worker. The difficulty in making the correct adaptation, often comes from the lack of knowledge of the injuries that they can cause and in which part of the machine they can occur.

With this theme, the present work uses an inference model, based on Fuzzy Logic, to measure the degree of risk of machines and equipment from variables predisposed in ANBNT: NBR 14153: 2013. Relevant Severity (S), Frequency and / or time of exposure to danger (F), Possibility of avoiding danger (P) were used as relevant variables.

The model is based on the category table in ANNEX B of ABNT NBR14153 / 2013.

The fuzzification variables and their linguistic values are shown in Table 2.1.

Table 2.1

System Relevance Functions

INPUT VARIABLES	POSSIBILITIES	**CAT** - Risk Category **Language Value** (OUTPUT)
Severity of Injury (S)	S1	B CAT1 CAT2 CAT3 CAT4
	S2	
Frequency exposure to danger (F)	F1	
	F2	
Possibility to avoid the damage (P)	P1	
	P2	

Note: CAT is the output linguistic variable, it is the degree of risk.

Source: Author (2020)

The Figure 1, illustrates the implementation of the risk degree simulation model according to ABNT NBR14153/2013 in its ANNEX B.

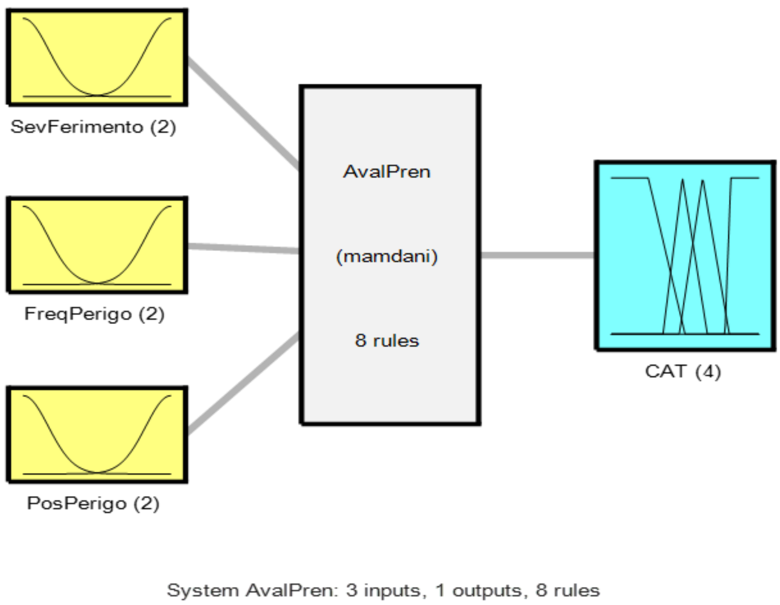

Figure 1 - Input and output variables of the proposed model

Source: Author (2020)

The variables of entry and exit of the system are previously defined by ABNT NBR14153 / 2013 in its ANNEX B, the definition of the category will be given by the set of entries according to previous knowledge of the machine and its possible accidents. Therefore, the system variables can be described as follows:

a) Severity of injury S - (SevFerimento): this variable analyzes the injuries caused to the employee in case of any type of failure in the machine's control system. This categorization must take into account the severity of the accident: bruises and / or lacerations without complications should be classified as S1, in situations of amputation and even death, they should be classified as S2. Usually S1 involves reversible injuries, which cause temporary work incapacities, while S2 is considered serious, with no possibility of reversal of the injury, permanently curtailing work capacity or even resulting in death.

Figure 2 illustrates that the fuzzification of this variable is the bell function.

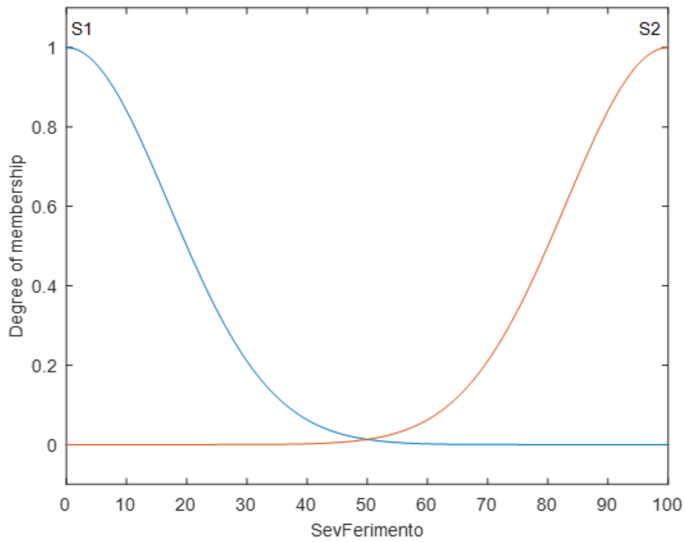

Figure 2 - SevFerimento Variables (Severity of Injury)
Source: Author (2020)

b) Frequency and / or time of exposure to danger F - (FreqPerigo):there is usually no time specification, the analysis continues taking into account whether the worker is frequently or continuously exposed to danger, F2 must be chosen. Machine operators who must place and remove parts from inside the machine, for example, are constantly exposed to danger, so the choice would be variable S2. Figure 3 shows the fuzzification of this variable.

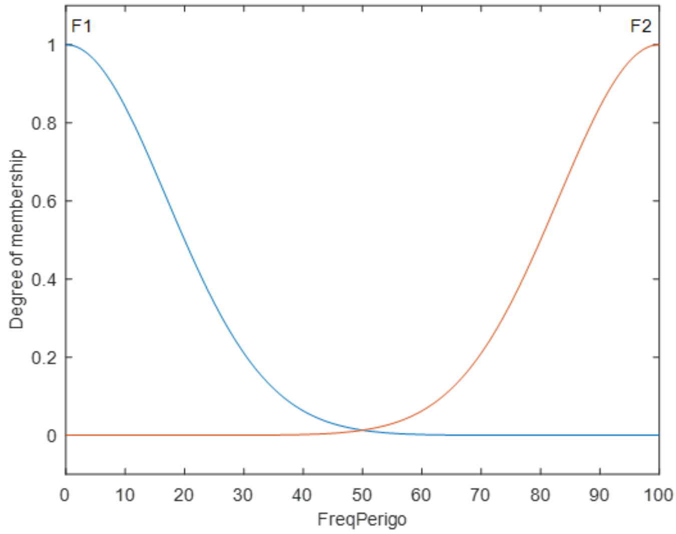

Figure 3 - FreqPerigo variables (frequency and / or time of exposure to danger)
Source: Author (2020)

c) Possibility to avoid danger P - (PosPerigo): this parameter takes into account the possibility of avoiding the danger when it appears, before the actual accident occurs. Some aspects must be taken into account, for example:

- **Is the operation carried out with or without supervision?**
- **Is the operation performed by specialists or non-professionals?**
- **How fast does the danger appear - quickly or slowly?**
- **Could the possibility of avoiding the danger be by escape or by the intervention of third parties?**
- **What are the practical safety experiences related to the process?**

The subcategory P1 should only be chosen in real cases in which the accident can be avoided or its effect significantly reduced, whereas P2 must be used when there is no chance of avoiding the accident.

Figure 4 illustrates the fuzzification of this variable, and like the previous ones, it follows the bell function.

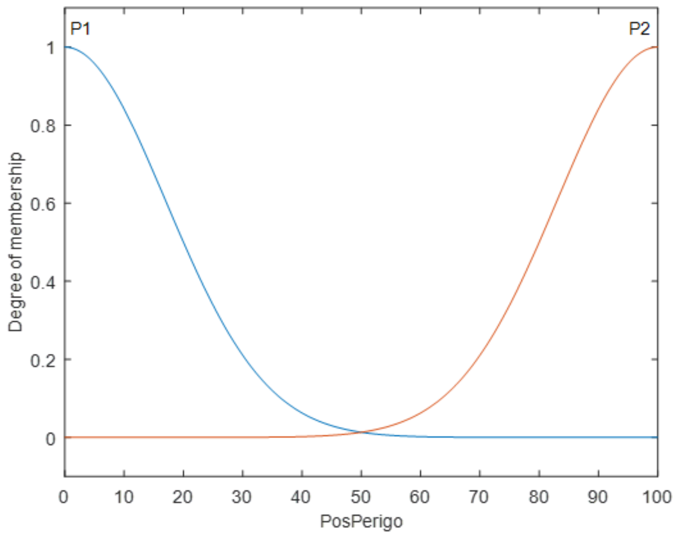

Figure 4 - PosPerigo variables (Possibility to avoid the danger)

Source: Author (2020)

d) Risk Category - CAT: This variable results in the degree of risk of the machine being analyzed. The result of this interaction is triangular, as illustrated by the fuzzification in figure 5.

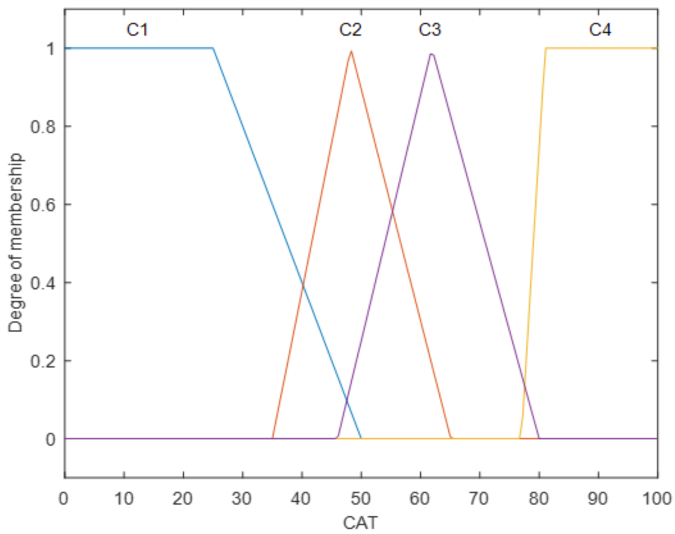

Figure 5 - Output variables - CAT (machine risk category)

Source: Author (2020)

The set of inference rules of this application, resulted in 8 combinations that can be seen in the illustration of table 2.1.

Table 2.1

Rules of the proposed model

1.If (SevFerimento is S1) and (FreqPerigo is F1) and (PosPerigo is P1) then (CAT is C1) (1);

2.If (SevFerimento is S1) and (FreqPerigo is F1) and (PosPerigo is P2) then (CAT is C1) (1);

3.If (SevFerimento is S1) and (FreqPerigo is F2) and (PosPerigo is P1) then (CAT is C1) (1);

4.If (SevFerimento is S1) and (FreqPerigo is F2) and (PosPerigo is P2) then (CAT is C1) (1);

5.If (SevFerimento is S2) and (FreqPerigo is F1) and (PosPerigo is P1) then (CAT is C2) (1);

6.If (SevFerimento is S2) and (FreqPerigo is F1) and (PosPerigo is P2) then (CAT is C3) (1);

7.If (SevFerimento is S2) and (FreqPerigo is F2) and (PosPerigo is P1) then (CAT is C3) (1);

8.If (SevFerimento is S2) and (FreqPerigo is F2) and (PosPerigo is P2) then (CAT is C4) (1);

Source: Author (2020)

2.2 Fuzzy Inference for the proposed model

The degree of risk of a press can vary from 1 to 4 and depends on the analysis performed, conditions of the machinery and experience of the operator. These factors influence the final result, and can hide serious safety problems if the study is not done in detail.

In order to help in the more accurate judgment of the degree of risk, the 3 characteristics were used to judge the degree of risk in machines, using as a basis Annex B of ABNT NBR14153 / 2013, and from these, pertinence functions were created.

The range used was from 0 to 100, corresponding to each of the two possibilities 50% chance of being selected during the analysis.

The combination of these membership functions will result in degrees of risk that can be seen in Table 3.1.

Table 3.1

Result of combinations of membership functions

Grade From Risk	Combination of Possible membership functions
B	S1
1	S1
2	S2-F1-P1
3	S2-F1-P2 S2-F2-P2
4	S2-F2-P2

Source: Author (2020)

It is noted that the degree of risk has two distinct combinations, being defined only by the type of injury that the employee may suffer during his working period.

2.3 Rules applied

As shown in table 3.3, each combination results in a degree of machine risk. For the proposed analysis of this study, the choice was the hydraulic press where its operation, as explained previously, serves for cycles, that is, each cycle is completed after started, thus making the machinery of high degree of risk, as it is impossible to avoid the accident when the machinery is not properly fitted with the normative safety items. The degree of risk for this machinery is the highest in the normative risk category, 4, analysis for this machinery is serious injury, which can even be death, the operator's frequency in the machinery is considered constant because in its a large majority the operator stays throughout his shift in the equipment, placing and removing performed parts, needing to insert hands and arms into the machinery where he presses, making it impossible to rescue the person alive or intact, because after pressing this machinery does not disarm if the equipment is turned off, responding for cycles it continues the work until its final position. Accidents in these cases are always, amputation, tearing, and in more extreme cases, death.

2.4 Case study

The data for implementing this was obtained in a company in the thermoplastic branch of the Industrial Pole of Manaus.

A small press (a baler) was used to carry out this analysis, the data were tested using the inference model comparing before and after adaptation, thus showing the effectiveness of the proposed model.

A first analysis was carried out with the machinery before adaptation, without the safety devices installed, verifying points of attention and risk / danger. From these data, the proposed inference model was used and the degree of risk in which the machinery is found was verified.

After this first approach, we proceed to the second simulation, right after the suitability of the press. The safety items installed were mentioned and again their data were inserted in the proposed inference model to verify the new degree of risk of the machine.

Within these analyzes it was possible to verify whether or not the machinery had a considerable reduction in the degree of risk, migrating from step 3 to degree 1 of risk, the lowest in the table in ANNEX B of ABNT. According to Annex B - ABNT NBR 14153: 2013, the lower the CAT, the greater the safety of the machine, and it is at this stage that it is intended to reach, so that there are no accidents that incapacitate or even culminate in the death of employees.

When analyzing the baler press illustrated in Figure 6, it appears that it in its initial state had few safety items, thus not guaranteeing the safety of the company's employees.

Figure 6 illustrates the machinery that is the object of this study and some safety problems detected according to normative items. The items in disagreement with ABNT NBR 14153 follow:

Figure 6 - Baling press without visible procedure.
Source: Author (2020)

- The operating procedure is not visible on the machine.
- Condition the corrective and preventive maintenance procedure of the machines;

Figure 7 - Floor demarcation.
Source: Author (2020)

- Lack of proper demarcation of the floor.

Figure 8 - Fixing the machinery.
Source: Author (2020)

- Machinery is not attached to the floor.

Figure 9 - Signaling.
Source: Author (2020)

- Missing sign indicating PPE's to be used

Figure 10 - Sensing.
Source: Author (2020)

- C heck the sensing that is in doubtful condition. Apparently, it is inoperative due to some impact suffered.

Figure 11 - Electrical panel and electrical controls
Source: Author (2020)

- Perform proper grounding on the machine followed by a report, according to NBR-5419, NBR-5410 and NR-10.
- Inadequate electrical control box according to regulatory standard NR10

Applying these security flaws found in the equipment, in the proposed fuzzy inference model, we have the following result:

Table 5.1

System Relevance Functions before adjustment

Accidents possible	Severity Of Injury (S)	Frequency exposure to danger (F)	Possibility to avoid the damage (P)	Value linguistic (Exit)
Sprain	S1	F1	P1	CAT 1
Amputation	S2	F2	P1	CAT 3
Shock	S2	F2	P1	CAT 3
Sis. Fuzzy%	74%	81.3%	35.5%	63%

Source: Author (2020)

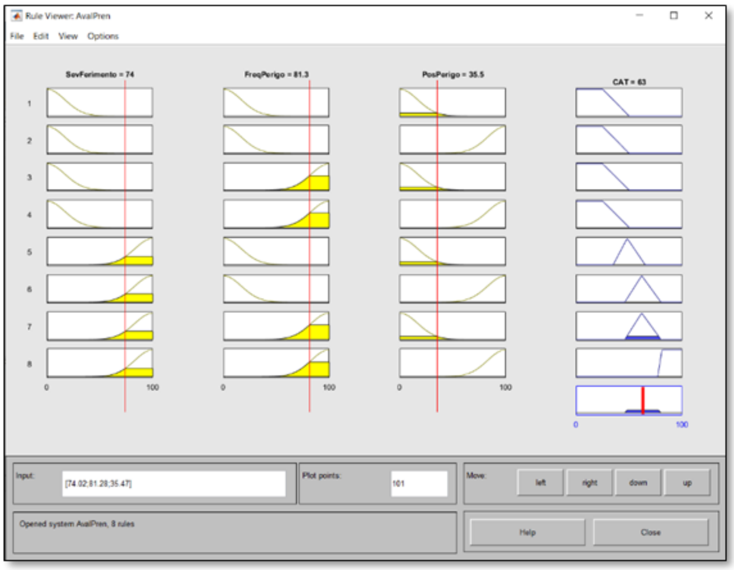

Figure 12– Rules viewer

Source: Author (2020)

The rules viewer illustrated in figure 12 shows that CAT is 63%, that is, CAT 3. In the conditions found in the machinery, there are two types of accidents that require changes in the safety of the equipment, amputation and shock as they give the machinery a degree of risk 3 (CAT 3).

Amputation for access to the pressing area of the press, in the removal of the burden from the machinery, which can be avoided.

The model fuzzy for the data obtained in the initial stage of the hydraulic press, it is illustrated in figure 13.

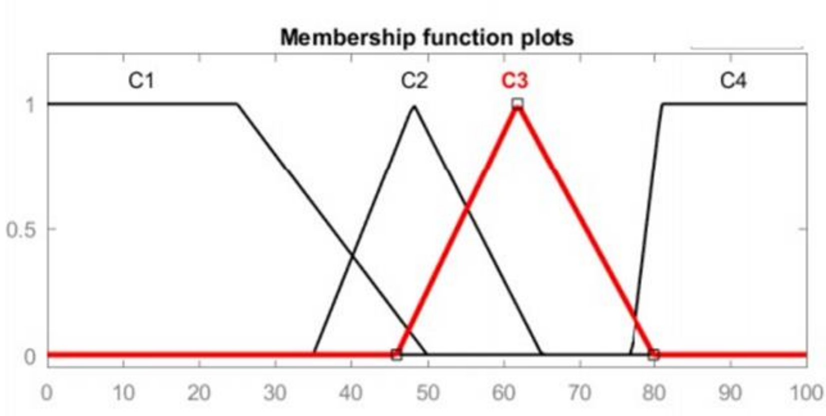

Figure 13 - Press risk category before adjustment.
Source: Author (2020)

As part of the suitability, an electromagnetic interlock sensor was placed on the material input door of the press, so it can only be operated with the door closed, the electrical frame reformulated, resized, the wiring changed and the control buttons changed. Press feet fixed to the floor without risk of the machinery tipping during operation.

After adapting the machinery, eliminating the unsafe conditions found initially, the modification illustrated below is verified and again the mathematical model is used to evaluate the new category of safety of the machinery.

Figure 14 - Machining fixation.
Source: Author (2020)

Figure 15 – Sensing
Source: Author (2020)

Figure 16 – Electrical
Source: Author (2010)

After adaptation, the concepts of the model were again applied to find the new risk category (CAT) of the machinery according to table 5.2;

Table 5.2

System Relevance Functions after adjustment

Accidents possible	Severity of Injury (S)	Frequency exposure to danger (F)	Possibility to avoid the damage (P)	Value linguistic (Exit)
Sprain	S1	F1	P1	CAT 1
Amputation	S1	F2	P1	CAT 1
Shock	S1	F2	P1	CAT 1
Sis.Fuzzy%	22.6%	22.1%	35.5%	24.1%

Source: Author (2020)

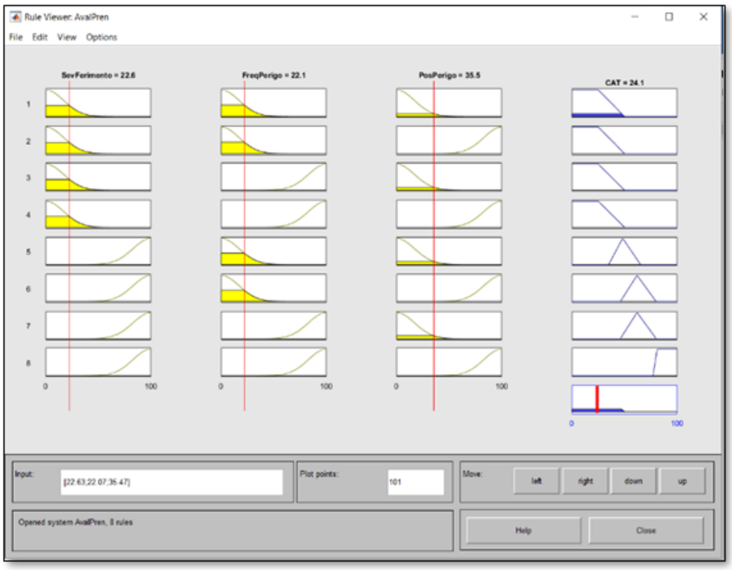

Figure 17– Rules viewer

Source: Author (2020)

The new risk category is CAT 1, making the equipment suitable for handling. The rules viewer shown in figure 17 shows that CAT is 24.1%, that is, CAT 1.

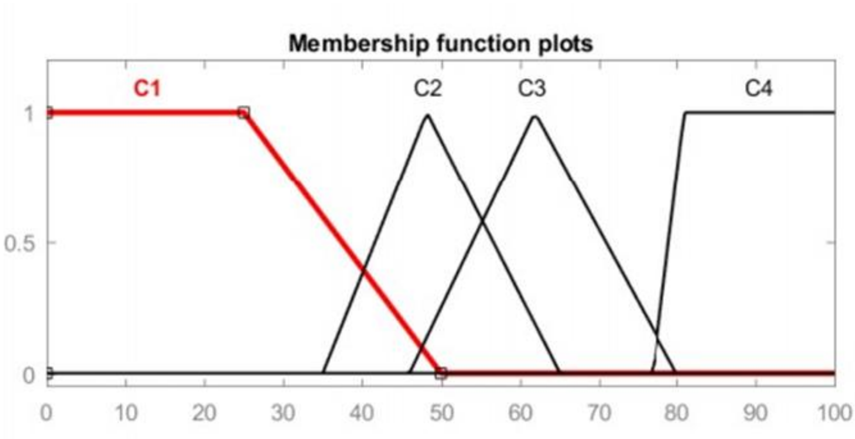

Figure 18 - Press risk category after adjustment.

Source: Author (2020)

The more severe the analysis reference used (S2, F2, P2), the greater the degree of risk of the machine.

When analyzing Figure 18, it appears that when the frequency of exposure to danger and the severity of the injury are low, the CAT (risk category) will also be low, the same occurs if it represents the frequency of exposure to danger and the severity of the injury is high, CAT tends to be a high degree.

In figure 19, there is a surface window generated by the matlab of the study model proposed, where it can be observed that the greater the severity of the injury, the longer the employee's exposure to the equipment during their workday, the greater the degree of risk of this machinery and the greater the need to adapt this equipment.

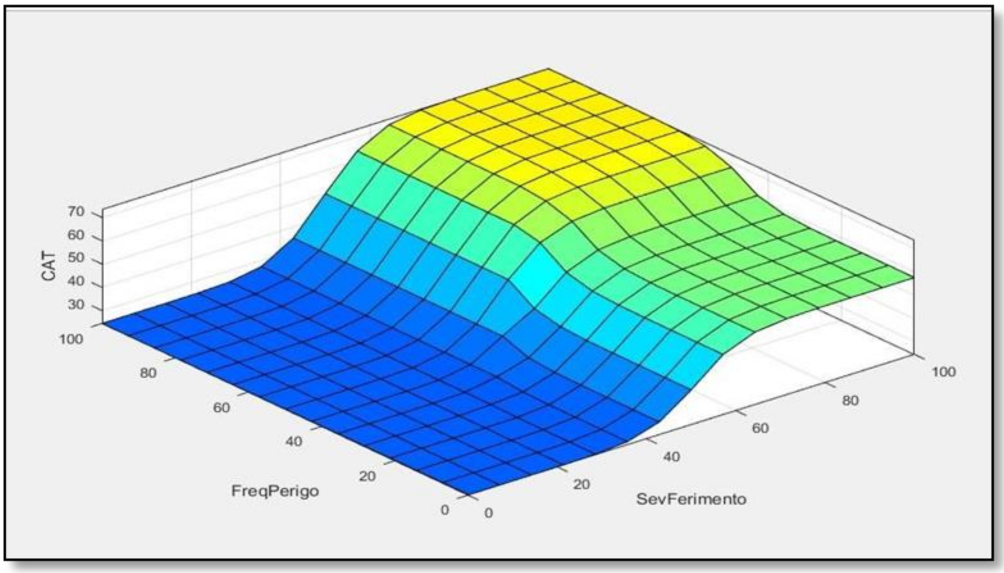

Figure 19 - Surface Analysis of the Degree of Risk.
Source: Author (2020)

3. Conclusion

Applying the model in logic Fuzzy, the true degree of risk of the machine is verified, before and after the adaptation, in the case in question the degree of risk has reduced from risk level 3 (CAT3) to risk level 1 (CAT1), this means that the machinery is if suitable for handling, accidents that could occur before adaptation will not happen because the safety devices attached to the machinery guarantee the operator's safety.

The reduction of two degrees of risk in machinery implies a lot of changes in the structure and concept of safety, training of personnel in the use and safe handling, coupling of sensors and safety rails, preventive and predictive maintenance scheduled and fulfilled, all of these and others concepts were applied so that the machinery could reach an acceptable level of safety, thus preserving the physical and mental integrity of the employees.

With the use of this tool, it is possible to analyze with greater speed and precision to what degree the machinery is found and to what degree of risk the same machinery is found after adaptation, regardless of the experience and technical knowledge that the analyzer may have.

The knowledge of the entire work process, of the dynamics of the employee's job on the machine to be analyzed brings a lot of contribution to the final result of the analysis, as it delivers to the analysis tool concrete and realistic data with the final result the degree of real risk. of the machine, however the tool allows any lay person to perform analysis on the same machinery and find the same result, since the window of possibilities for analysis is beyond the simple “yes” or “no” of the usual logic.

The ideal is that a first analysis is carried out before adapting the machinery, and another analysis after analyzing the results obtained and the adequacy carried out.

A proposal for the evolution of this tool is to create a chatbot system in the form of a questionnaire for the operator to carry out these analyzes during his working day, to integrate the results to a database in order to have a real-time notion of all the machines in the factory parking, thus streamlining decision making by those responsible for maintaining the safety level of their employees.

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