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USE OF TAGGING AND CRITICALITY MATRIX AS PARAMETERS FOR MAINTENANCE OF HYDROMECHANICAL EQUIPMENT OF THE OITICICA DAM IN JUCURUTU/RN

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Abstract. *A simple failure in the functioning of a system containing hydromechanical equipment used in dams can negatively affect their performance, or even result in a complete interruption of the water intake's sanitary flow, requiring the need to stop for maintenance. The present work aims to present a failure criticality analysis method, which can be used to evaluate the general maintenance of the hydromechanical equipment of the Oiticica dam in Jucurutu/RN, in order to avoid defects and stoppages. For this, the following elements will be described: the team that will work on the maintenance plan, the manufacturing monitoring, the hydromechanical equipment that will require periodic maintenance; the tagging of the listed equipment; and the elaboration of the criticality matrix. The selected team for this purpose was essential given the practical and professional knowledge of the subject. The tagging of the equipment, in addition to being organizational, helped to understand the order of assembly and operation. The results of the criticality matrix suggested the most critical equipment to be carried out maintenance, the equipment that needs faster maintenance, and the components that do not need so much concern, serving as a parameter for the financial direction of maintenance.*

Keywords: *Hydromechanical equipment, Oiticica dam, equipment tagging, criticality matrix, maintenance.*

1. INTRODUCTION

The Oiticica Dam in Jucurutu/RN aims to regularize the course of the Piranhas River, becoming part of the complex of works aimed at the use of water resources generated in its water basin (KL, 2019), also being part of the São Francisco River Integration Project with Northeastern Hydrographic Basins - PISF, through a supplementary water intake (Engecorps, 2000).

The supplementary water intake of the Oiticica dam is intended to carry water from the Piranhas River upstream through pipes and low-pressure hydromechanical equipment, retaining floating solid bodies, and regulating a flow rate of 50m³/s, as demanded by the Armando Ribeiro Gonçalves dam. (KL Engineering, 2019).

In order for the water intake to operate continuously without interruptions, the proper functioning and preservation of the hydromechanical equipment must be carried out (Cirilo, 2008), prioritizing the cases of greatest impact, through analyses, as in the case of the matrix of criticality with the use of tagging.

Tagging is the identification of equipment used in certain industrial applications, in the respective production areas. This labeling process has been increasingly applied, due to the need for sectoral control of materials and organization of maintenance stops (Viana, 2002).

Tagging is also the basis of the maintenance organization, as it is the mapping of the manufacturing unit, improving the traceability of processes, and also facilitating the identification of equipment in need of maintenance.

The level of criticality serves to indicate which equipment is more complex in terms of predictive maintenance needs, since data relating to safety, cost, production and quality are collected, making it possible to identify potential or early-stage failures. (Marques et al, 2006).

Michelon (2019) in his master's thesis, proposed a matrix for criticality analysis in a production line of an industry, determining the preventive maintenance technique as being the most ideal and with best usage, which generated financial savings, according to Fabro (2003), carrying out a maintenance plan properly conducted by a systematic method and directed to the matrix's critical equipment, provided an increase in time availability and eradication of a greater number of downtimes.

This work aims to carry out the tagging and criticality matrix of the hydromechanical equipment of the supplementary water intake of the PISF of the Oiticica dam in Jucurutu/RN, in order to be taken as a parameter in the elaboration of the maintenance plan, thus avoiding excessive stops in the operation of the water intake.

In the elaboration of the criticality matrix, although the NBR 55000 (2014) standard defines a "critical asset" as being an asset with the potential to significantly impact the achievement of the organization's objectives, there are no standards to assemble the levels, parameters, scenarios and criticality classes. In this work, the criticality levels and parameters were defined by the real maintenance needs, being an innovative point to those normally used in production industries, since it is not an industry, but a dam water intake.

2. METHODOLOGY

The activities developed throughout this work are described; those were carried out, for the development of the tagging and criticality matrix of the hydromechanical equipment of the supplementary water intake, belonging to the São Francisco River Integration project of the Oiticica dam in Jucurutu/RN.

Field visits were made at the Oiticica dam in Jucurutu/RN, to better understand the maintenance and monitoring needs of hydromechanical equipment and improve practical theoretical knowledge.

Similarly, a technical visit was carried out to a factory in Taubaté/SP, to check the progress of the manufacturing process of the equipment that makes up the hydromechanical system of the supplementary water intake of the Oiticica Dam (São Francisco River Integration Project).

EIT Encalso is the construction consortium of the dam, while KL Engenharia e Serviços was the company that carried out the elaboration of the hydromechanical project. Quanta Consultancy (QS/OITICICA) is the company responsible for managing the manufacture and assembly of the hydromechanical equipment, and Hydrostec is the company responsible for manufacturing the equipment.

2.1 Team formation

The responsibility for conducting maintenance studies must be delegated to an individual, but the accurate and complete study must be done by a team. In general, the team must contain the necessary types of knowledge and approach (Fogliatto, 2009).

A team responsible for conducting the maintenance studies of the hydromechanical equipment was formed, composed of engineers from different fields, who have a direct connection with the design and manufacture of the equipment.

2.2 Equipment listing and selection

As there are many sorts of hydromechanical equipment present in the Oiticica dam and not all of them have a need to prepare a maintenance plan, the equipment to be analyzed was selected and noted in a list, based on the information contained in the hydromechanical project. For the selection of equipment, the following criteria were used: the application of the equipment, their dimensions and weight.

2.3 Tagging

In the tagging stage, the equipment was initially mapped at the water intake unit, being separated according to the dam, water intake, and location, in order to receive maintenance.

Observing the arrangement of the equipment along the water intake, the structuring of the tagging of the water intakes was carried out, in which it was divided into 3 main levels of tags, as illustrated in Fig. 1.

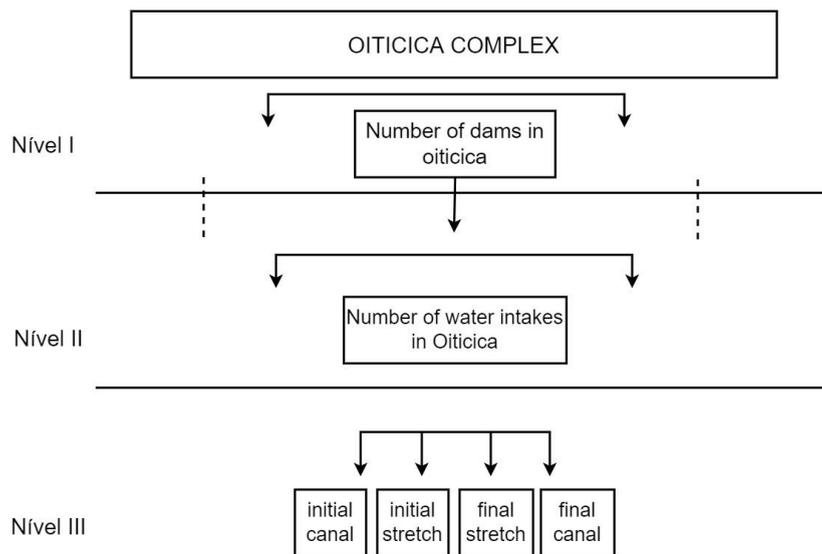


Figure 1. Flowchart with tagging levels.

The equipment was numbered according to this preliminary separation, and then a TAG was prepared, also taking into account the name of the component being visualized in the original project.

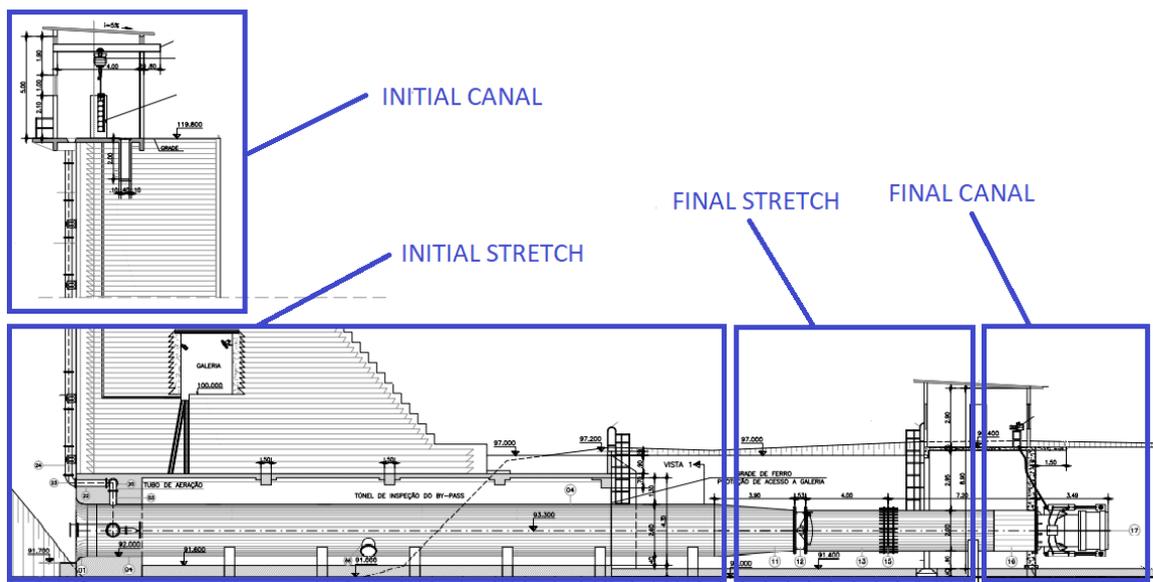


Figure 2. Original design of the Oiticica water intake with a breakdown of the division.

Equipment was tagged according to the identified levels, receiving codes for each associated level. At level III, the equipment was separated into the initial canal, initial stretch, final stretch and final canal. A table was made containing the name of the equipment and its adopted TAG.

2.4 Criticality or priority

In order to analyze the criticality of the equipment that was tagged, the first step consisted in defining the categories of the criticality matrix and classes, similarly to what was done by JIPM (1995), in Tab. 1.

Table 1. Classification of categories

S	Potential risk of an accident when failure occurs	high risk	Medium and low risk	discarded risk
Q	Risk of losses, claims and rework	high risk for losses and rework	average risk for losses and rework	low or discarded risk
O	Equipment operating time	24h/day	8h to 24h/day	<= 8h/day
IF	Process impact during equipment failure	interrupts the entire production process	It does not interrupt processes, but generates losses	There is no significant risk
F	Equipment failure frequency	greater than 1 failure for 2 months	One failure every 2 months or 6 months	less than one failure every 6 months
M	Average repair time (ART)	ART > 2 hours	0.5h < ART < 2h	ART < 0.5h

Source: Adapted from JIPM (1995).

In this work, the categories were divided into 5 groups, namely: safety, production, quality, maintenance cost and maintenance time, adapting JIPM's (1995) choices to the reality of this equipment.

These chosen categories were classified into four risk classes, with an equivalence score ranging from zero to three, in which the lowest value implies greater individual criticality. The classes were different from the ABC classification of JIPM (1995), adapted to the reality of the needs of a water intake.

Each piece of equipment was evaluated regarding its importance for the functioning of the water intake, answering the questions of the chosen categories, accumulating scores, and obtaining the general criticality through Eq. (1).

$$C = N_{safety} * N_{quality} * N_{production} * N_{reliability} * N_{time} \quad (1)$$

Once the individual criticality was calculated, the equipment was classified into high, medium and low criticality, as described in Tab. 2, identified according to the scores.

Table 2. Criticality classification according to score

Final grade	Criticality	Description of asset criticality (classes)
0-55	A=High	This is the most important equipment: It interrupts the production process/reduces production capacity; affects human safety and the environment; affects quality; there is no backup; increases monthly maintenance costs by more than 20%
56-161	B=Medium	This is equipment of intermediate importance: It affects production in a recoverable way; causes short-term injuries and/or ecological disturbance; requires product reprocessing; there is a backup; increases from 10% to 20% of monthly maintenance costs.
162-243	C=Low	This is equipment of low importance: It does not affect production; causes mild, controllable harm to health and the environment; does not affect the quality of the product; there is a backup; It does not significantly affect maintenance costs.

Source: Teles (2019).

The general criticality was calculated and classified according to Tab. 2, the equipment was ranked, and compared with the parameter established by Teles (2019), as shown in Fig. 3.

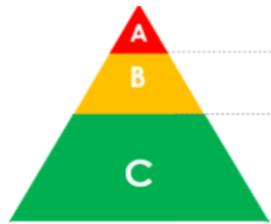


Figure 3. Pyramid of criticalities and parameters to be met. Adapted from Teles (2019).

Only 20% can be classified as criticality A, between 30 and 40% criticality B, and between 40 and 50% criticality C. If these conditions are not met, the scoring methodology needs to be redone, changing the answers to the categories of individual criticality.

Once the criticality matrix is established, based on it, maintenance priorities and interventions will be described, in order to avoid failures and great losses.

3. RESULTS AND DISCUSSION

The formation of the team is a step of great importance, as it requires the participation of professionals who are knowledgeable in the field, both in practical and theoretical terms. Starting from this premise, professionals from fields directly related to the design, use and application of the dam equipment were chosen, considering the manufacture, inspection and management, actively involving representatives from different areas, as shown in Tab. 3, stimulating the exchange of ideas between the involved sectors.

Table 3. Team formed for maintenance study.

Nome	Academic education	Responsibility
Alexandre Mateus	Mechanical Engineer	Maintenance plan
Victor Nôga	Civil Engineer	Oversight
Francisco Almeida	Mechanical Engineer	Management
Paulo Moura	Civil/Mechanical Engineer	Manufacturing
Valmar Costa	Mechanical Engineer	Project

For some of the members, pseudonyms were used to avoid identification, although the guidelines for the formation of the central group were kept.

The understanding of the design, manufacture and operation of hydromechanical equipment is of paramount importance for the development of the criticality matrix and indications of the necessary maintenance, therefore, technical visits were made to the Oiticica dam in Jucurutu/RN and the Hydrostec factory in São Paulo, as illustrated in Fig. 4.



Figure 4. Technical visit: (a) Oiticica Dam and (b) Hydrostec Factory.

In these activities, it was possible to observe the real environment of a company in full operation, in addition to verifying its dynamics, organization and all the theoretical factors implicit to it.

The analyses made from a technical visit contribute to optimize workers' performance, in addition to being important as didactic-methodological resources, resulting in knowledge in an articulated way between theory and practice (Costa and Araújo, 2012).

Outside the scope of this work, a descriptive report was prepared, containing information on production, quality, deadlines and quantitative percentage of progress, in order to identify deviations, their magnitude and provide subsidies for those responsible for corrective actions to act.

As there is a great quantity of hydromechanical equipment present in the Oiticica dam, only the equipment that needs maintenance was selected, from the point of view of its operation and complexity, making the work more objective and directed. Tab. 4 lists these devices.

Table 4. Hydromechanical equipment to be analyzed

N°	Brief description
1	W310 x 52 beam in carbon steel
2	Mechanical device for panel suspension
3	Storage over well
4	3.7m x 3.7m stoplog in structural carbon steel
5	Gate shielding and frame
6	Stainless-steel-laminated upstream protection grille
7	DN 2,600 mm bell mouth in carbon steel
8	500 mm and 150 mm gate valve
9	DN 2,600 mm piping in structural carbon steel
10	Pipe support in concrete with carbon steel base and graphite paper
11	Manhole with 600 mm blind cap in carbon steel
12	Concentric reducer from DN2,600 mm to 2,000 mm
13	DN 2000 mm butterfly valve
14	DN 2,000 mm pipe
15	DN 2,000 mm dresser joint
16	2000 mm flange
17	DN 2,000 mm fixed cone valve
18	DN 2,000 mm curve for valve fixation, in structural carbon steel

This equipment was selected among the existing totals, because: they are the ones that most need accurate maintenance, they play a more important role in the water intake, they have a long history of failures and problems, they are of high purchase value, and they need more specialized interventions.

For most of these items, because they are complex in operation, there is an operation and maintenance manual made available by the manufacturer itself, but which contains specialized information, which in practice are not followed.

As there are several dams in the Oiticica complex, and since for each dam it is also possible that there are water intakes, the tagging of the equipment following TAG levels was adopted by the design of Fig. 5.

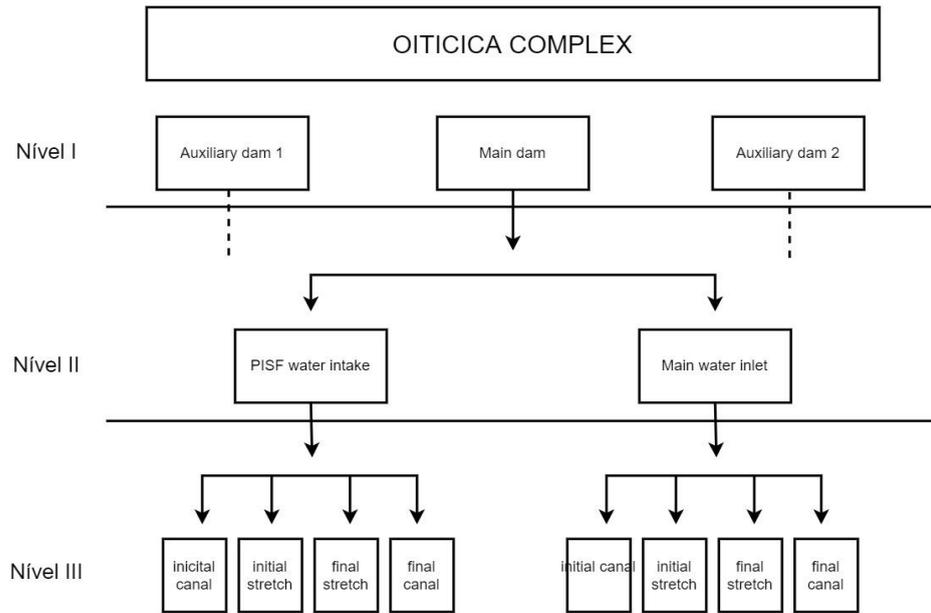


Figure 5. Concept adopted for the levels of tagging.

The Oiticica complex is divided into three large dams, called auxiliary dam 1, main dam and auxiliary dam 2. In this study, those are respectively represented by the initials “B1”, “BP” and “B2”.

At level II, each dam was broken down into its water intakes, where it is necessary to follow the logic of each process, assigning the code “PISF” for the PISF water intake or “TP” for the main water intake. .

The division of level III was designed having in mind the characteristics and location of the equipment along the water intake, as well as the rationalization of management, divided into four areas according to the positioning of the equipment, separated into initial canal “CI”, final canal “CF”, initial section “TI”, final section “TF”, as the project illustrates in Fig. 6.

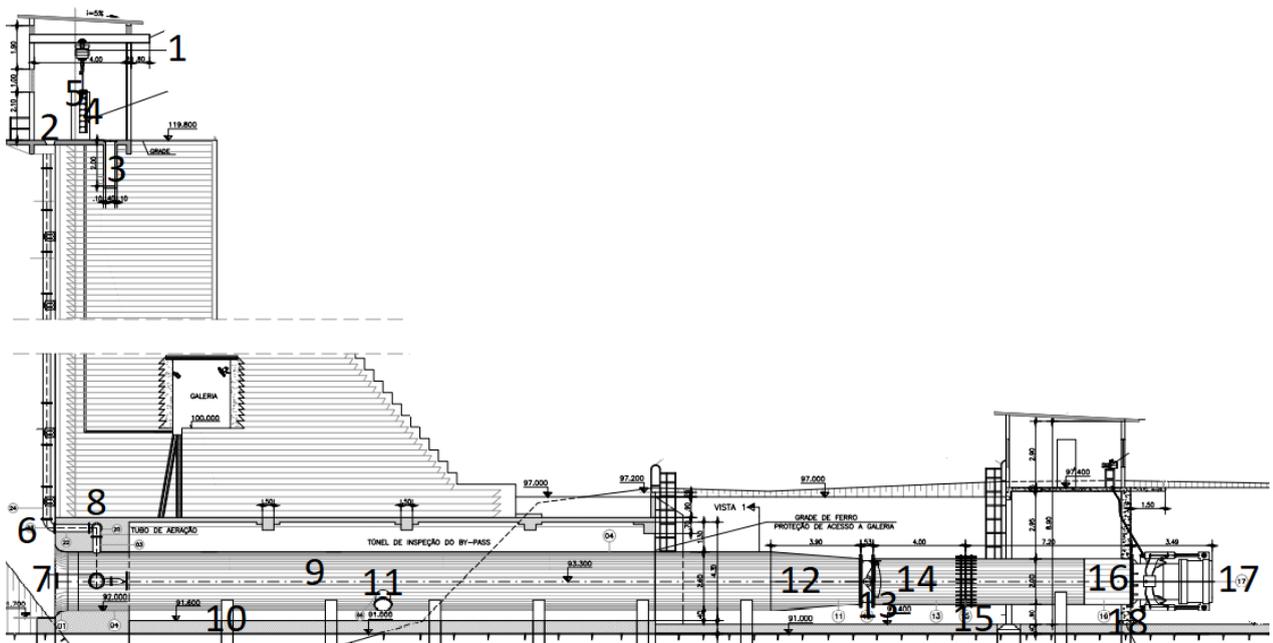


Figure 6. Project with identification of the analyzed hydromechanical equipment.

In the scheme shown above, the numbers indicate the position of the equipment along the water intake, represented only in this project view. It is also noteworthy that, later, modifications were made to the positioning of this equipment and application improvements, which were not included in the scope of this research work.

The division at level III is considered the most important part for this work, which focuses on the water intake of the PISF of the Oiticica dam, which is already being concluded.

Process mapping aims to obtain information and understand the issues related to it, in addition to determining the interdependencies in the relationships between activities and establishing criteria for continuous improvement. The classification of manufacturing steps as value-adding or non-value-adding activities is also important for a better understanding of the process (Fabro, 2002).

Equipment tagging is shown in Tab. 5, which contains the identification of each equipment, given the division at level III.

Table 5. Equipment tagging

LEVEL III	UP	EQUIPMENT	TAG
CI - INITIAL CHANNEL	01	W-beam	BP-PISF-CI-VP-001
	02	Device for panel suspension	BP-PISF-CI-CAL-002
	03	Storage over well	BP-PISF-CI-PE-003
	04	Stoplog	BP-PISF-CI-CE-004
	05	Gate shielding and frame	BP-PISF-CI-BM-005
TI - INITIAL STRETCH	06	Protection grille	BP-PISF-TI-GP-006
	07	Bell mouth	BP-PISF-TI-BC-007
	08	Gate valve	BP-PISF-TI-RG-008
	09	DN 2,600 mm pipe	BP-PISF-TI-TB-009
	10	Pipe support	BP-PISF-TI-AT-010
	11	Manhole	BP-PISF-TI-BV-011
TF - FINAL STRETCH	12	Concentric reducer	BP-PISF-TF-RC-012
	13	Butterfly valve	BP-PISF-TF-VBS-013
	14	DN 2,000 mm pipe	BP-PISF-TF-TB-014
	15	Dresser joint	BP-PISF-TF-JD-015
CF - FINAL CHANNEL	16	2000 mm flange	BP-PISF-CF-FL-016
	17	Fixed cone valve	BP-PISF- CD-VDS-017
	18	Curve for valve fixation	BP-PISF-CD-GM-018

The table containing the tagging of the equipment favored a greater organization and understanding of the operation and positioning of the equipment along the water intake, so that it can even be made available in the control room of these, for use and control by the operator.

The tagging, although it is used most of the time in the production industries, was adapted well to the reality of operation of a water intake, as it provided an organizational identification of the equipment, for a work of great dimensions and of estimated importance.

There are no standards to assemble the parameters, levels, scenarios and classes of the criticality matrix, which allows the engineer to be creative to evaluate what is interesting to analyze within the criticality matrix, taking as an example ISO 55000 (1997) , or other proposed matrices such as that of Teles (2007).

The definition of the urgency of the service is a human activity, and depends on criticism of the maintenance area. On the other hand, the classification of the equipment, through its position tags, adopts a rule covering the impact of the equipment coming to a halt, in the aspects of safety at work, environment, product quality and plant operability (Viana, 2002).

The categories defined in Tab. 6 (with their respective weights indicated), were used as criteria for evaluation, similarly to what was done by Teles (2007) and Viana (2002), and adapted to the reality of the present research.

Table 6. Criteria of the Criticality Matrix

Safety and Environment	Production	Quality	Maintenance cost	Maintenance Time	Score
If the equipment fails, it will cause risk of death and/or cause serious damage to the environment.	If the equipment fails, it will interrupt the production process causing loss of profit and induced costs	If the equipment fails, it will irretrievably affect the customer experience	If the equipment fails, its repair will increase monthly maintenance costs by 30% or more.	Months	0
If the equipment fails, it will cause minor injuries and short-term ecological disturbance.	If the equipment fails, it will interrupt the production process or irrecoverably reduce production capacity.	If the equipment fails, it will irrecoverably affect the quality of the product.	If the equipment fails, its repair will increase monthly maintenance costs by 20% or more.	Weeks	1
If the equipment fails, it will cause minor and controllable damage to health and the environment.	If the equipment fails, it will interrupt the production process or reduce production capacity in a recoverable way.	If the equipment fails, it will affect the quality of the product in a recoverable way.	If the equipment fails, its repair will increase monthly maintenance costs by 10-15%.	Days	2
If the equipment fails, it will not pose a risk to safety and the environment.	If the equipment fails, it does not interrupt the production process or reduce production capacity.	If the equipment fails, it will not affect the quality of the product.	If the equipment fails, its repair will represent less than 10% of the maintenance costs.	Hours	3

These chosen categories were similar to those adopted by Teles (2007), but with changes, because in the consulted literature and other references the tagging generally refers to the manufacturing industry, which has a different form of operation when compared to that of a dam's water intake system.

In a similar way, the adopted scores were conceived by taking into account the use and application of the equipment; lower values indicate a greater individual criticality for that category.

The final values obtained from Eq.(1) were classified into high, medium and low criticality, following the parameters in Tab. 7, in view of the failure to comply with the parameters of Fig. 3 when using the table obtained from the literature (namely Tab. 2).

Table 7. Criticality classification according to score

Score	Criticality	Description of asset criticality (classes)
0-4	A=High	The most important equipment: it interrupts the production process/reduces production capacity; affects human safety and the environment; affects quality; there is no backup; increases monthly maintenance costs by more than 20%
5-72	B=Medium	Equipment of intermediate importance: It affects production in a recoverable way; causes short-term injuries and/or ecological disturbance; requires product reprocessing; there is a backup; increases from 10% to 20% of monthly maintenance costs.
73-243	C=Low	Equipment of low importance: it does not affect production; causes mild, controllable harm to health and the environment; does not affect the quality of the product; there is a backup; it does not significantly affect maintenance costs.

Source: Adapted from Teles (2019).

The criticality for each equipment was calculated by adopting the scores above, choosing the individual values shown in Tab. 8, resulting in the global values for the criticality of each equipment, shown in the last two columns of the table.

Table 8. Criticality matrix of the hydromechanical equipment of the Oiticica dam

NAME	N _{Security}	N _{Production}	N _{Quality}	N _{Cost}	N _{Maintenance}	CRITICITY	SITUATION
Fixed cone valve	1	0	1	1	0	0	A (High)
Butterfly valve	1	0	1	1	0	0	A (High)
Stoplog	1	1	2	2	1	4	A (High)
DN 2,600 mm pipe	1	1	1	2	3	6	B (Average)
DN 2,000 mm pipe	1	1	1	2	3	6	B (Average)
Dresser joint	1	2	1	3	1	6	B (Average)
Concentric reducer	1	1	1	2	3	6	B (Average)
Protection grille	1	3	2	3	2	36	B (Average)
Bell mouth	3	2	2	3	2	72	B (Average)
W-beam	2	2	2	3	3	72	B (Average)
Gate valve	3	3	2	3	2	108	C (Low)
Curve for valve	3	3	2	3	2	108	C (Low)
flange	2	2	3	3	3	108	C (Low)
Manhole	3	3	2	3	2	108	C (Low)
Device for suspension	2	3	2	3	3	108	C (Low)
Storage over well	3	3	2	3	2	108	C (Low)
Gate shielding	3	2	3	3	3	162	C (Low)
Pipe support	3	3	3	3	3	243	C (Low)

From the table, it is notable that the most critical cases were the fixed cone valve, the butterfly valve and the stoplog, being considered as highly critical.

The fixed cone and butterfly valves are considered to be extremely critical equipment, as they are responsible for the entire discharge control of the water intake (ORBINOX, 2022). The fixed cone valve, through the opening of its shutter, controls the system flow based on the current water level of the dam, so that it can work within the parameters of the project, and it maintains the speed of the fluid within safety limits (AWWA C-516, 2021). The butterfly valve, on the other hand, has the function of blocking the system and guarantees access to the fixed cone valve in case it needs maintenance. These two represent approximately 50% of the total amount destined to the hydromechanical equipment of the Oiticica dam (Hydrostec, 2022), and therefore require greater attention from the operation and maintenance team, because in a possible failure in one of them, robust values would need to be spent, and the eventual replacement would take at least 4 months after the purchase process.



Figure 8. (a) Main equipment, fixed cone valve and (b) water pipe.

The stoplog was also among the most critical equipment of the Oiticica dam, since: a failure in its movement structure will result in the non-opening of water flow along the entire gallery; a failure in the structure will cause a large pressure differential, with the risk of breaking the internal structures, in addition to the loss of flow control; a failure in the seal will allow the passage of water in small flows; as well as other adverse effects.

Another component considered to be of great criticality were the pipes themselves, as they are responsible for conducting water along the entire gallery, being designed to contain pressures, tension and mechanical stress. This equipment undergoes a series of welds, with ultrasound control and checks throughout its manufacture and installation. In Brazil, there is a known history of leaks and ruptures in pipes and their respective flanges.



Figure 8. Fabricated: (a) gate and (b) anchor tubing.

Equipment considered to be of medium criticality also plays an important role in the operation of the water intake, but they are not as critical for human safety or the environment - parameters that are of great value in this scenario.

The equipment of low criticality, for the most part, does not interfere significantly with the operation of the water intake, but is auxiliary for this purpose, providing safety, storage, support, pressure control, water conduction, and couplings.

Regarding the percentage of global criticality, 17% of the equipment was considered of high criticality, approximately 39% of medium criticality, and approximately 44% were of low criticality, these values being within the limits established in the literature by Teles (2007), shown in Tab. 1, which corroborates the change in the used parameters.

If the change in the adopted parameter intervals was not made according to Tab. 6, most of the equipment would be of criticality A, some of criticality B, and only two equipment of criticality C, which would not comply with the limits indicated by Teles (2007).

The criticality matrix proved to be of easy comprehension, indicating the equipment that is more critical in terms of safety, production, quality, cost and maintenance time, highlighting the components of highest priority for eventual maintenance.

From the perspective of process criticality, maintenance planning allows the use of a set of tools that make it possible to keep critical processes available for use for as long as necessary, taking as main basis the order of magnitude of the criticality matrix. Thus, the importance of maintenance planning in the proper treatment of critical processes must be emphasized (Fabro, 2002).

This plan must be guided by the criticality of the processes, aiming to direct efforts to the equipment related to highly critical processes, and saving efforts for the less critical ones (Fabro, 2003).

4. CONCLUSIONS

Therefore, the objectives of this study were achieved, as a criticality matrix was elaborated for the hydromechanical equipment of the Oiticica dam in Jucurutu-RN, containing the classification of the equipment with the greatest need for maintenance, following the criteria of safety, production, quality, cost and maintenance time.

The visits that were carried out were extremely important for technical-professional knowledge, providing a link between theory and practice, as the equipment was manufactured, supplied, assembled and installed, avoiding future problems in the maintenance itself.

The formation of the group for the elaboration of the maintenance and monitoring proposals was also of great benefit to the project, as it brought together different fields of knowledge and professionals from all concerned parts, contributed with greater proximity to the practice, and allowed the development of the criticality matrix.

The tagging of the equipment proved to be useful in providing a better organization when preparing the criticality matrix, in addition to a better understanding of the operation and positioning of the equipment along the water intake.

The criticality matrix showed itself to be an easily comprehensible table, with clear indication of the equipment that is more critical in terms of safety, production, quality, cost and maintenance time, highlighting the priorities for carrying out eventual maintenance, avoiding more critical problems.

As a future suggestion, it is recommended that the FMEA method be used for the maintenance of the hydromechanical equipment of the Oiticica Dam in Jucurutu/RN; the criticality matrix developed in this study can be applied for that purpose.

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