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# CONTRIBUTION TO THE IMPROVEMENT OF PUMPING SYSTEM RELIABILITY. CASE STUDY: BENI-HAROUN WATER PUMP STATION, ALGERIA

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***Abstract:*** *The use of system analysis techniques and the maintenance optimization becomes a necessity for increasing the equipment availability by reducing the frequency of failures. In this context, our research proposes a preventive maintenance plan to improve the reliability of a drinking water pumping station, located in the Dam of Beni-Haroun (Eastern Algeria). The objective of our study is to increase the reliability of the pumping system and consequently, to ensure a continuous production of drinking water distributed to six cities of Eastern Algeria, as well as to their bordering regions. For this purpose, a set of analyses techniques, including Structured Analysis and Design Technique (SADT), Failure Mode, Effect and Criticality Analysis (FMECA) and Pareto analysis, is used to identify the critical types of failure. The research results consist in the elaboration of some recommendations for the improvement of the reliability of the analyzed system.*

***Key words:*** *Preventive maintenance, reliability, FMECA, Pareto diagram, SADT, pumping station.*

## 1. INTRODUCTION

The main objective of a maintenance system is to minimize the failure of machines [1] and, if possible, to prevent it completely. Very frequent important failures will lead to large environmental damages in machines and will extremely increase the reparation cost. Maintenance should not therefore be considered as a cost center, but a profit generating function [2]. The second objective of the maintenance system is to be able to guess maintenance needs in advance and to plan these needs exactly. The third objective of the maintenance system is to keep the operation capacity of the system at a maximum level, by means of reducing the breaking period of critical machines [3]. Therefore, the benefits of a well-maintained machine include a lower rate of failures and downtime, cost efficiency and higher productivity.

The systemic analysis, is an interdisciplinary field relating to the study of objects in their complexity. Indeed, it allows the description of a study object in its environment, in its functioning, in its mechanisms and also in the interactions that result from these three aspects [4], [5] and [6]. The application of preventive maintenance allows the industrial company to increase its profit thanks to the reduction of the budget needed for maintenance.

Preventive maintenance is a type of the existing technical maintenance strategies. Preventive maintenance is described as maintenance of equipment or a system before fault occurs, thus not letting the breakdown to happen [7] and [8]. Preventive maintenance is carried out according to predetermined criteria, with the objective of reducing the probability of equipment failure during use, reducing downtime in the event of overhaul or breakdown and eliminating the causes of serious accidents. It is based on conformity checks, periodic monitoring to detect anomalies and carry out simple adjustments without the need for specific tools or stopping the production tool.

Any maintenance intervention has a financial impact. The cost analysis must highlight a gain

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in relation to the failures that can be avoided. It is also at this point that the company studies whether it should decide to move on to the more costly corrective maintenance stage [8].

A pumping station is a station used to pump water or more generally a fluid, such as oil for example. It can be used for several applications such as supplying water to canals, draining low-lying areas, and disposing of wastewater to the processing site.

In a pumping station, the pump is one of the indispensable elements. It is very rare that water can be transported from the point of collection to the consumers by natural way, it is necessary to raise the water and to discharge it with the help of a hydraulic pump. It is driven by an electric motor and reinforced by other equipment installed upstream and downstream of the pump.

The condition and availability of this equipment affects the operation of the pumping stations; it is difficult to monitor and evaluate the performance of the pumping system when the equipment is not functioning properly.

Therefore, a careful maintenance plan of water pumping station should be applied to ensure an uninterrupted operation The purpose of this maintenance plan is to minimize the failures [9], and if possible, to prevent them completely and, thus, to keep the operation capacity of the system by reducing the halting period of the pumping system at pumping station. In this context, we propose a methodology to improve the reliability and availability of this system. This methodology consists of three stages; the first consists of a functional analysis by the SADT method, the second in an analysis of failures by the FMECA approach [10] and finally in the prioritization of problems according to the number of their occurrence by the Pareto diagram [11], [12] and [13].

## 2. CASE STUDY: PUMPING STATION OF BENI HAROUN DAM

The water pump station examined in this paper is the water pumping station of Beni Haroun Dam in Algeria.

### 2.1 Overview

The Beni Haroun dam is a gravity type dam, located in the extreme north of the Wilaya of Mila, in the north-east of Algeria. With a height of 118 m, it was opened in 2003, it is the largest dam in Algeria with a capacity of 960 million m³ (Fig. 1). The Beni Haroun dam is equipped with a large raw water pumping station, with a capacity of 180 $m^3$ [20] and [21].

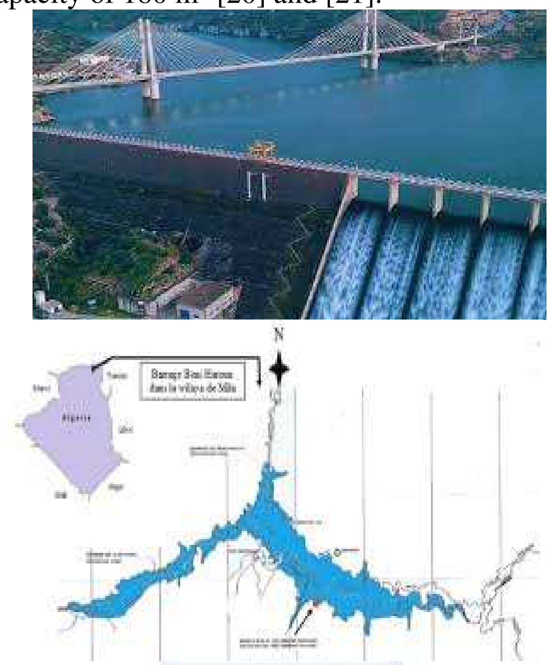

**Fig. 1.** General view of the Beni Haroun dam (Photo. Remini, June 2014)

### 2.2 Constitution of pump station

The water pumping station examined in this work is called SP1 (Fig.2). This station consists of four main sections [22] :

1- The power supply chamber.

2- The tank of resumption of the capacity 500 $m^3$.

3- Pumps and regulation chamber: equipped with three (03) identical electric Motor pump units mounted in parallel.

4- Anti-ram.

### 2.3 System description

The SP 1 station includes a machine room for the installation of the hydraulic machines. The dimensions of this room are:

Width =9m

Length=12.40m

Inside this room, three (03) centrifugal Moto Pump units in charge suck the water from the suction tank through a suction pipe and deliver it to the storage tank (Fig.2). At the level of the delivery and suction pipes contains different measuring devices and accessories with the following characteristics [23]:

a) Motor: its role is to transform electrical energy into mechanical energy.
b) Pump: ensures the pumping of water to the storage tank.

Technical specifications for the pump and the driver motor are shown in Tables 1 and 2 respectively.

*Table 1*

**Pump specifications (Reputed manufacturing, Industry Source)** [24]

| Type | Capacity of pump Q [m$^3$/h] | Rotationnel speed (rpm) | Head (m) |
|---|---|---|---|
| KSB | 468 | 1480 | 700 |

*Table 2*

**Motor specifications (Reputed Manufacturing, Industry Source)** [24]

| Type | Power (KW) | Current (A) | Frequency (Hz) |
|---|---|---|---|
| SIEMENS | 400 | 690 | 50 |

**Fig. 2.** View of SP1 station and Moto pump units

## 2.4 Data collection and analysis

Pumping system at stations are subjected to mechanical, electrical, and structural problems affecting the behavior, the efficiency, the safety and the reliability of these stations. This system has a clear effect on the performance and efficiency of the stations. The objective of this research is to develop the traditional maintenance system at SP1 station, which, among other things, waits for the breakdown to intervene, towards a maintenance system based on prevention.

The analysis confirmed the recommendation of the maintenance department that pumping system faults need to be targeted to improve the availability of the SP1 pumping station.

To conduct the reliability analysis, data on the history of faults and failures is required. The following sources were used; the National Agency of Dams and Transfers work order database (ANBT), the operator logbooks and operator/maintenance technician interviews.

At the beginning of the study, the pumping system and corresponding subsystems components are determined (motor, pump, etc.). Then, the failures are determined based on experts' opinion and the system database, which records the failures, occurred in the system. 5 experts are interviewed to gain the input data for the FMECA method. The experts are from three majors, namely Mechanical Engineering, Electrical Engineering and Environmental Engineering and their experiences are between 1 to 15 years.

The data available from both databases was sometimes incomplete. We have used the observation of the behavior of the equipment during the year 2020 at the SP1 station to make this information more reliable and complete.

## 2.5 Analysis of the maintenance of the Pumping station

The techniques used to analyze the maintenance of the pumping station were SADT, FMECA and Pareto analysis. This analysis allows us to examine patterns of failures related to each component in order to have the action to be taken.

In this section, the pumping system considered in this study is analyzed in three sections, namely motor sub-system, pump sub-system and control accessories sub-system. These three sub-systems have different number of components.

This analysis allows us to examine patterns of failures related to each component of various subsystems in order to have the action to be taken.

**Phase 1: The functional study (SADT method)**

Structured Analysis Design Technique (SADT) is a method of analysis to understand the main function of the system, what sub-functions it must perform and finally, how these functions are performed and the degree of their complexity.

The method is based on a graphical model. The modelling approach is top-down; from general behavior to detailed operation, focusing on system activity [25].

The description of a system is done in the form of a coherent sequence of diagrams:

- The highest-level diagram represents the purpose of the technical system.
- Each lower level diagram defines the sub-functions of the system as well as their relationships, their arrangement in the system.
- By convention, the highest level has the reference A-0 (A minus zero). This level A-0 is broken down into n boxes A1,A2,...An, which constitute the level A0, etc...

To define the pumping system, we used SADT method. Figure 4 shows node A-0 of SADT model of pumping system.

**Phase 2: FMECA Analysis**

The Failure Modes Effect and Criticality Analysis (FMECA) method is a quality tool for preventive analysis that allows the identification and treatment of potential causes of defects and failures before they occur.

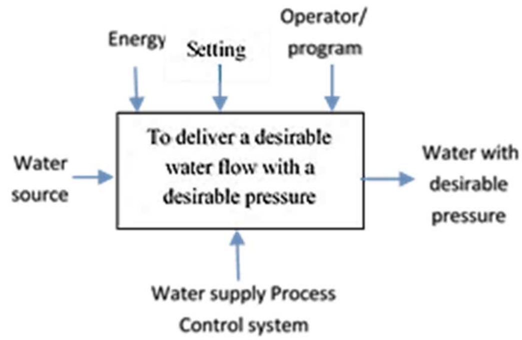


**Fig. 4.** Node A-0 of SADT model of pumping system

The FMECA method is a rigorous method of work very effective through the sharing of information and data [26], [27] and [28].

Based on the analysis of the normal operation of the selected system, and after locating the critical sections, it is advisable to undertake an analysis of equipment failures via an Analysis of Failure Modes and their Effects and Criticality, FMECA. The FMECA method aims to:

- to identify the causes and effects of potential failure of a process or a means of production.

- to identify the actions that can eliminate (or at least reduce) the potential failure.

The principle of the FMECA method is to identify all potential causes of each failure mode. Then, it is necessary to evaluate the criticality of the failure modes. The criticality is obtained by calculated the risk priority number (RPN) (Table 3) as follow [29]:

$$\text{RPN} = \text{severity (S)} \times \text{occurrence (O)} \times \text{detection (D)} \quad (1)$$

-The (S) rating: Concerning the consequences caused by the occurrence of the failure mode. Usually rated from 1 to 5.

-The (O) rating: Relating to the frequency of occurrence of the failure, this frequency expresses the combined probability of occurrence of the failure mode by the occurrence of the cause of the failure. The frequency F ranging from 1 to 4.

-The (D) rating: Relating to the possibility of detecting the failure (the couple: Mode-Cause of failure) before it produces the effect. The detection D is evaluated from 1 for a detectable failure, to 4 for an undetectable failure.

The RPN is used to rank and identify concerns or risks associated with the operation as a result of its design. This number will be used to prioritize which components should be evaluated by the team in order to reduce their calculated risk via corrective action or maintenance efforts. However, when the severity is high, regardless of the resulting RPN, immediate corrective action may be taken.

Four situations are taken in table 3:

- Green color indicates a negligible risk
- Yellow color indicates acceptable risk
- Orange color indicates an unwanted risk
- Red color indicates an unacceptable risk

*Table 3*

**Safety matrix**

| **RPN** | ***0-<12*** | ***12-<24*** | ***24-<36*** | ***36-<48*** |
|---|---|---|---|---|
| *Impact* | *Negligible* | *Acceptable* | *Un-wanted* | *Un-acceptable* |
| *Level* | | | | |

The actions taken consist of:

-Classify the problems encountered;
-Propose the improvement;
-Calculation of the new criticality.

The actions carried out are decided by the working group in order to eliminate any critical points. From the criticality value, we can classify the problems in descending order and divide them into different categories (Table 4).

The decision on the type of corrective action to be taken should be guided by the most critical factor in the criticality score.

*Table 4*

**Criticality table**

| **Criticality value** | **Policy of maintenance** |
|---|---|
| RPN <12 | Put under patching |
| 12≤RPN<24 | Putting under preventive at low frequency |
| 24≤RPN<36 | High frequency preventive setting |
| 36≤RPN<48 | Search for improvement |

In this section, we will use the operating results of the pumping system equipment to actually apply the theory to really apply the theory already mentioned before. The data for this application are collected from the historical records of each equipment.

An extract of the FMECA analysis is presented in tables 5, 6 and 7.

The RPN ranged from 12 to 48, as listed in Tables 5, 6, and 7. The majority of the examined risks were judged to be unacceptable (RPN > 36) [29] and [30].

*Table 5*

**Extract from the FMECA of the pump**

| Analysis of Failure Modes and Causes and their Criticality Effects | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ***System:*** *electric Moto pump*<br>***Sub-system:*** pump | | | | | | | | | |
| **Component** | **Function** | **Failure mode** | **Cause of failure** | **Local effect** | **Effect of the failure on the system** | Criticality | | | |
| | | | | | | **D** | **S** | **O** | **RPN** |
| The wheel | Transforming water | Cavitation | Air bubbles | Holes in the wheel | Stopping the operation | 3 | 4 | 3 | 36 |
| Bearings | Rotation and support | wear | Foreign substance | Vibration, efficiency reduction | To stop the entire system | 2 | 4 | 2 | 16 |
| | | Crack | Fatigue | Friction and vibration | | 3 | 2 | 2 | 12 |
| Impeller | Transferring energy | Pitting marks Blade damaged | Bog generation around the impeller corrosion | Impeller damaged Impeller loss on shaft | | 3 | 4 | 4 | 48 |
| ………… | …………. | ………….. | ………….. | …………….. | ………………….. | | | | … |

*Table 6*

**Extract from the motor FMECA**

| Analysis of Failure Modes and Causes and their Criticality Effects | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ***System:*** *electric Moto pump*<br>***Subsystem:*** motor | | | | | | | | | |
| **Component** | **Function** | **Failure mode** | **Cause of failure** | **Local effect** | **Effect of the failure on the system** | **Criticality** | | | |
| | | | | | | **D** | **S** | **O** | **RPN** |
| Rear End bell | Maintenance and Connection of the motor components | Loss of oil pressure, Separation elements of the engine | Breaking, Game, Sensor malfunction, Pierced hose, Crack | Accelerated wear and tear moving parts of the motor | Stop the operation | 3 | 4 | 4 | 48 |
| Rotor | Energy conversion | Shaft rupture, Fissured rotor parts | Vibration, Material fatigue, Eccentricity, Warm and damage bearings | Friction between motor components | Blockage | 3 | 4 | 4 | 48 |
| Bearing | Rotation and support | Warn, Non fixed material coupling | Insufficient lubrication | Vibration, Undesired noise | Degraded performance | 2 | 3 | 2 | 12 |
| | | Motor no functioning properly | Undesired particle presence, Overload | Friction between motor and components | Blockage | 3 | 2 | 4 | 24 |
| ………… | ………… … | …… | …………… | ……… | ………… | | | | … |

*Table 7*

**Extract from the FMECA of the control accessories**

| **Analysis of Failure Modes and Causes and their Criticality Effects** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ***System:*** *electric Moto pump*<br>***Subsystem:*** control accessories | | | | | | | | | |
| **Component** | **Function** | **Failure mode** | **Cause of failure** | **Local effect** | **Effect of the failure on the system** | Criticality | | | |
| | | | | | | **D** | **S** | **O** | **RPN** |
| **Valve** | Set the flow | Wear and tear | Aging | Malfunctioning | Irregular pumping | 2 | 3 | 3 | 18 |
| **Non-return valve** | Ensures the passage of the fluid in one direction only | Wear and tear | Aging, High water pressure | Pressure reduction | Visual | 2 | 3 | 3 | 18 |
| ………… | ……….. | …….. | ……………. . | ……………… | ……… | | | | … |

The possible failure modes were analyzed for each of the components of the three sub-systems. The major failure modes identified, and the resulting critical issues for each subsystem, are summarized below. Figures 5, 6, and 7 detail the failure criticality assessment of the individual subsystems.

1) Sub-system 1: Pump

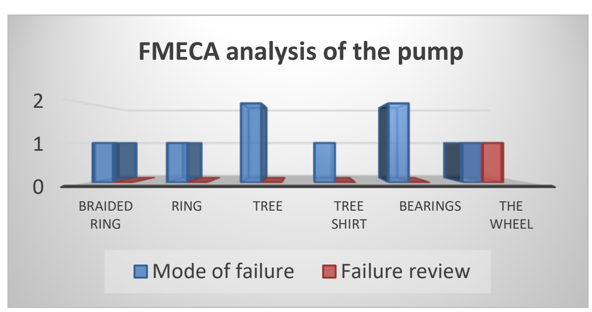


**Fig. 5.** Result of the FMECA analysis of the pump

2) Sub-system 2: Motor

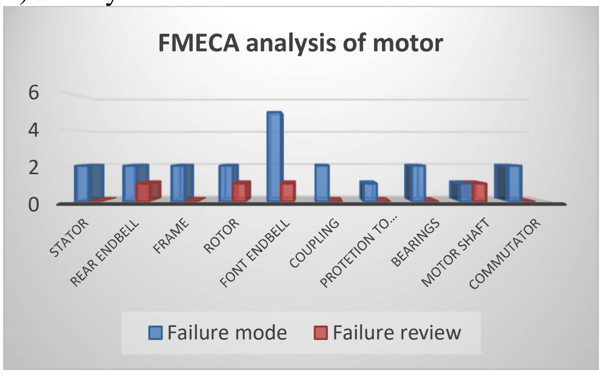


**Fig. 6.** Result of the FMECA analysis of motor

## Synthesis of FMECA analysis:

As a synthesis, Table 8 and Figure 8 illustrates the hierarchy of the number of failures of the components of each subsystem in relation to the criticality levels of each failure.

3) Sub-system 3: Control accessories

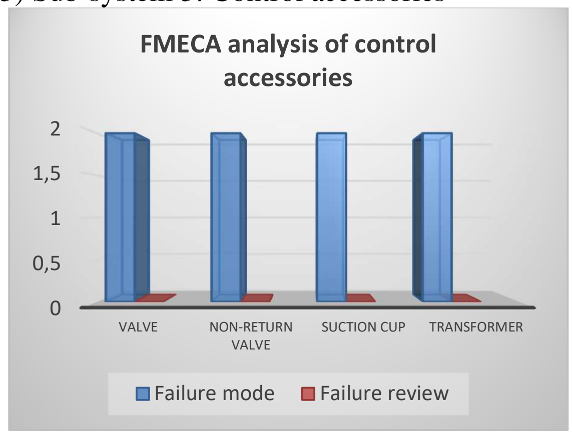


**Fig.7.** Result of the FMECA analysis of the control accessories

*Table 8*

**Summary of subsystem failure analysis**

| Subsystem | Number of high criticality components | Number of criticality components to be monitored | Number of components with acceptable criticality | Number of components with negligible criticality |
|---|---|---|---|---|
| Motor | 2 | 2 | 4 | 0 |
| Pump | 1 | 1 | 4 | 1 |
| Control accessories | 0 | 0 | 1 | 3 |

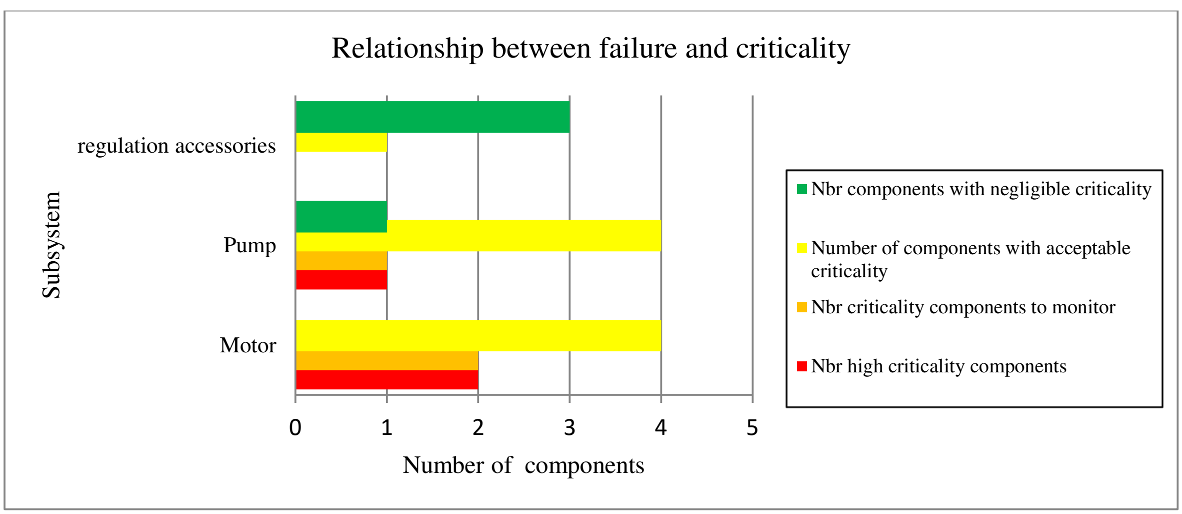


**Fig. 8.** Relationship between the number of failures and their criticality of subsystems

## 2.6 Phase 3: Pareto analysis

To draw up an action plan that meets the expectations of the maintenance and spare parts supply department, we used the Pareto diagram. This denier is a simple way to classify phenomena in order of importance. It is useful for identifying the causes on which to act in priority to significantly improve the situation. This will avoid wasting energy on what has little impact. It is based on the 80/20 principle and used in any continuous improvement process. That is to say that acting on 20% of the causes makes it possible to resolve 80% of the effects [31].

In this analysis, the organs are ranked in descending order according to their criticality. The cumulative and the cumulative percentage of each organ are determined afterwards. The following tables (9, 10 and 11) show the components of the subsystems (centrifugal pump, motor and control accessories) and their corresponding criticalities.

## A/Pareto analysis of pump

The Pareto curve makes it possible to divide the elements of the system studied into three classes: Class A representing the most critical elements (PNR $\geq$ 12), this class represents almost 74% of the cumulative criticality (Figure 9). The constituent organs of this class are:
Impeller; Shaft sleeve; Bearing; and Shaft.

*Table 9*

**ABC ranking for pump components**

| Pump components | Criticality | % | Cumulative percentage % | ABC Ranking |
|---|---|---|---|---|
| Impeller | 36 | 29% | 29% | A |
| Shaft sleeve | 24 | 20% | 49% | A |
| Bearing | 16 | 13% | 62% | A |
| Shaft | 15 | 12% | 74% | A |
| Bearing2 | 12 | 10% | 84% | B |
| Wear rings | 12 | 10% | 93% | B |
| Packing ring | 8 | 7% | 100% | C |
| Total | 123 | | | |

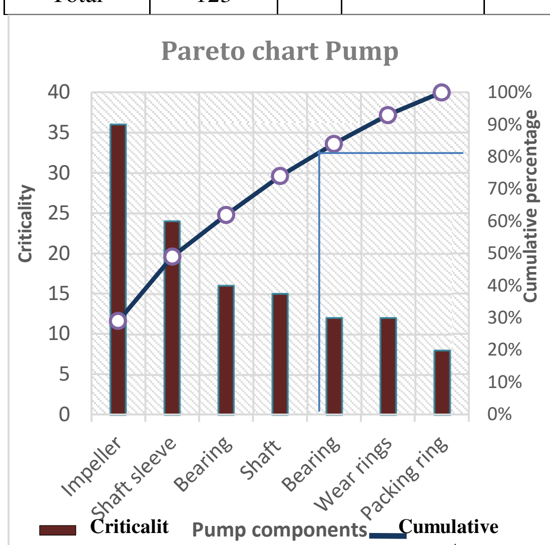


**Fig. 9**. Pareto chart for criticality (pump)

## B/Pareto analysis of motor

From Figure 10, it is observed that major problems (79%) are caused due to failure of: Rear Endbell; Font Endbell; Rotor; Shaft; Stator; Protection to Inner; and Bearing.

*Table 10*

**ABC ranking for motor components**

| Motor components | Criticality | % | Cumulative percentage % | ABC Ranking |
|---|---|---|---|---|
| Rear Endbell | 48 | 15% | 15% | A |
| Font Endbell | 48 | 15% | 29% | A |
| Rotor | 48 | 15% | 44% | A |
| Motor Shaft | 36 | 11% | 55% | A |
| Stator | 32 | 10% | 65% | A |
| Protection to Inner | 24 | 7% | 72% | A |
| Bearing | 24 | 7% | 79% | A |
| Commutated | 16 | 5% | 84% | B |
| Brush assembly | 16 | 5% | 89% | B |
| Frame | 12 | 4% | 93% | C |
| Bearing | 12 | 4% | 96% | C |
| Coupling | 12 | 4% | 100% | C |
| **Total** | 328 | | | |

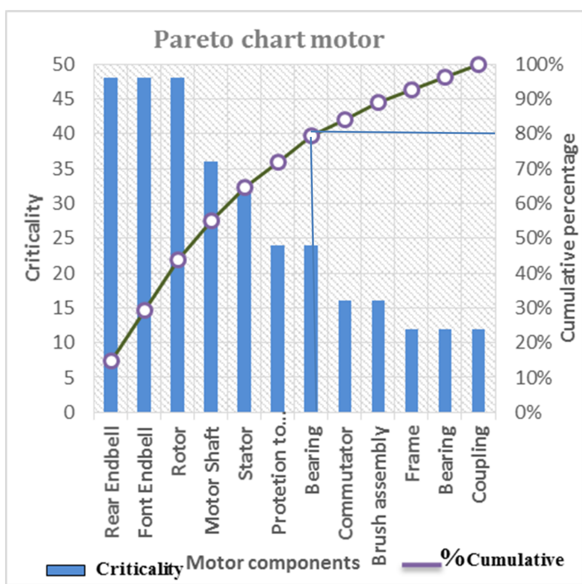


**Fig. 10.** Pareto chart for criticality (motor)

### C/Pareto analysis of control accessories

From Figure 11, it is observed that major problems (75%) are caused due to failure of air relief, valve and check valve.

*Table 11*

**ABC ranking for components of control accessories**

| Control accessories components | Criticality | % | Cum. Perc. % | ABC Ranking |
|---|---|---|---|---|
| Air relief valve | 24 | 30 % | 30% | A |
| Valve | 18 | 22,50% | 52% | A |
| Check valve | 18 | 22,50% | 75% | A |
| Transformer | 12 | 15 % | 90% | B |
| Air relief valve | 8 | 10 % | 100% | C |
| **Total** | 80 | | | |

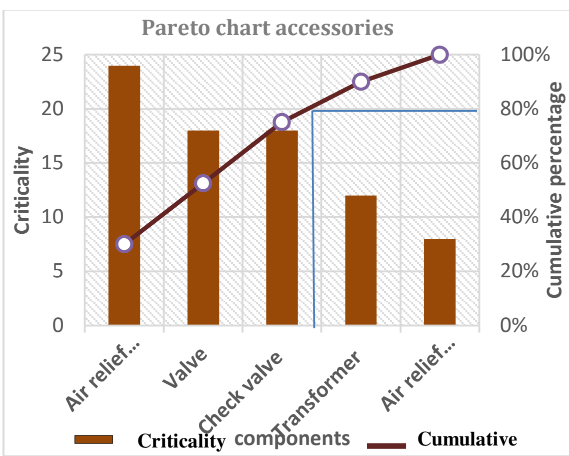


**Fig. 11.** Pareto chart for criticality (control accessories)

## 3. IMPROVING SYSTEM PERFORMANCE: RECOMMENDATIONS

After determining the most critical elements using the FMECA, preventive maintenance operations will be implemented. Consequently, two types of actions are listed, controls, which are mostly, level 1 or 2 operations, and maintenance which concerns maintenance levels 1 to 4.

The main decisions, measures and orientations taken according to the technical and organizational aspects, are essentially summarized by:

- Elimination of what seems to be the least critical in order to evaluate the results in a very targeted maintenance plan and establishment of a feedback system;
- Establishment of a model for close monitoring of critical equipment in terms of surveillance and interventions in order to optimize pre-established maintenance plans;
- Establishment of a troubleshooting checklist for critical equipment;
- Division of maintenance personnel into homogeneous and autonomous groups, each of which is responsible for the operation and maintenance of a specific set of equipment;
- Designation of a team that will be responsible only for preventive work;
- In addition, the dates of the maintenance operations must be adjusted according to:
    - Climatic conditions;
    - Vacation periods (absent staff);
    - Peak periods (in spring, restarting of sanitation works, cleaning of the station after winter...).

In order to provide recommendations for improving the performance of the system and subsystems, the second step is to analyze all failures with criticalities to be monitored or critical.

These proposed actions aim at making the criticalities of the components of the subsystems, declared, high or to be monitored, (levels between 32 and 48), more acceptable or negligible.

These actions, therefore, will have an effect, either on the level of their probability of occurrence, or on the level of severity caused (Figure 12).

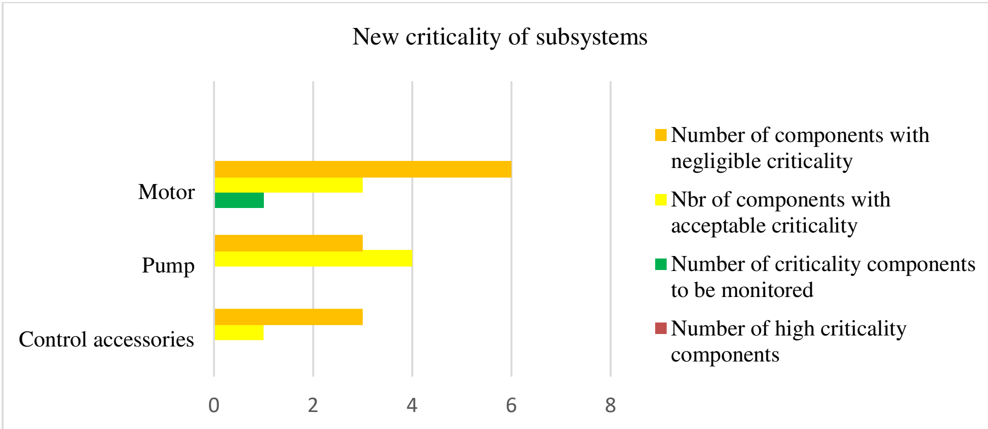


**Fig. 12.** Relationship between the number of failures and their new criticality of subsystems

## 4. CONCLUSION

During this work, SADT method, FMECA study and Pareto diagram are carried out on a pumping system of the water pumping station in order to improve the maintenance function. Our studies begin with a decomposition of the system based on the functional analysis in order to achieve functional decomposition to identify the components of each equipment (motor, pump, control accessories). Each equipment is studied separately to identify its failures by applying the FMECA method. A Pareto is performed to target faulty components and thus to be a decision-making tool for the preventive maintenance tasks to be selected. This allowed us to propose a set of preventive actions for the most critical components of each equipment on the station.

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**Contribuție asupra îmbunătățirii fiabilității unui sistem de pompare.**
**Studiu de caz: Stația de pompare Beni-Haroun, Algeria**

**Rezumat:** Utilizarea tehnicilor de analiză a sistemelor și optimizarea mentenanței devine o necesitate pentru creșterea disponibilității echipamentelor, prin reducerea frecvenței de apariție a defecțiunilor. În acest context, cercetarea noastră propune un plan de mentenanță preventivă pentru îmbunătățirea fiabilității unei stații de pompare a apei potabile, situată în Barajul Beni-Haroun (Estul Algeriei). Obiectivul studiului nostru este de a creste fiabilitatea acestui sistem și, în consecință, de a asigura o producție continuă de apă potabilă, distribuită în șase orașe din estul Algeriei, precum și în regiunile limitrofe acestora. În acest scop, pentru a identifica defecțiunile critice este utilizat un set de tehnici de analiză, care include Structured Analysis and Design Technique (SADT), Failure Mode, Effect and Criticality Analysis (FMECA) și Pareto. Rezultatele cercetării constau în elaborarea unor recomandări pentru îmbunătățirea fiabilității sistemului analizat.

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