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By:

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Using the FMECA method to support multi-criteria decision on the selection of maintenance procedures

Publicly defended on 07/06/2026in front of the jury composed

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Dedications

First and foremost, I thank Almighty Allah for giving me the strength and patience to accomplish this humble work.

I dedicate this dissertation to my beloved parents, whose endless support, encouragement, and prayers have always been the source of my motivation and success.

To my family and friends, thank you for your constant support and for standing by my side throughout this academic journey.

To all of them, I dedicate this humble achievement.

Abdelghani

Dedications

I dedicate this humble work to everyone who supported and encouraged me throughout my academic journey, and to all those who gave me love, motivation, and hope to reach this stage.

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Imad Eddine

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Abstract

This study aims to apply and improve the Failure Modes, Effects, and Criticality Analysis (FMECA) method on a high-pressure pump used in the Ifri Gara water treatment station in order to evaluate and prioritize failure modes according to their criticality. First, the traditional Risk Priority Number (RPN) method based on occurrence, severity, and detection criteria was applied. The results revealed limitations in the conventional approach, particularly the occurrence of identical RPN values for different failure modes despite differences in their actual impact.

To overcome these limitations, the Analytic Hierarchy Process (AHP) was integrated to determine the relative weights of the criteria and develop the FMECAw model. In addition, maintenance cost was introduced as an extra criterion within a multicriteria model (FMECAmc). The obtained results showed that integrating weights and maintenance cost improved the accuracy of failure classification and supported more effective and realistic maintenance decision-making, contributing to enhanced reliability and operational performance of the pumping system.
Keywords:AHP,Failure Analysis,FMECA,High-Pressure Pump, Maintenance CostMaintenance.

استخدام منهجية FMECA المدعمة باتخاذ القرار متعدد المعايير في اختيار إجراءات الصيانة

ملخـص:

تهدف هذه الدراسة إلى تطبيق وتحسين منهجية تحليل أنماط وتأثيرات وحرجية الأعطال (FMECA) على مضخة الضغط العالي بمحطة إفري قارة لمعالجة المياه، من أجل تقييم الأعطال وترتيبها حسب درجة الخطورة. تم في البداية تطبيق الطريقة التقليدية المعتمدة على رقم أولوية المخاطر (RPN) باستخدام معايير الحدوث والشدة والكشف، حيث أظهرت النتائج وجود قيم متساوية لبعض الأعطال رغم اختلاف تأثيرها الحقيقي.

ولتجاوز هذه المحدودية، تم دمج طريقة التحليل الهرمي (AHP) لتحديد أوزان المعايير وتطوير نموذج (FMECAw)، ثم إضافة معيار تكلفة الصيانة ضمن نموذج متعدد المعايير .(FMECAmc) وقد أظهرت النتائج أن إدماج الأوزان وتكلفة الصيانة ساهم في تحسين دقة تصنيف الأعطال ودعم اتخاذ قرارات صيانة أكثر فعالية وواقعية، مما يساعد على تحسين موثوقية وأداء نظام الضخ.
الكلمات المفتاحية:

FMECA،AHP، رقم أولوية المخاطر، تكلفة الصيانة، مضخة الضغط العالي، تحليل الأعطال، الصيانة.

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Acronyms

ABC	Activity-Based Costing / ABC Method
AHP	Analytic Hierarchy Process
AFNOR	Association Française de Normalisation
CEN	European Committee for Standardization
CI	Consistency Index
Ct	Maintenance Cost Criterion
D	Detection
EN	European Standard
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects, and Criticality Analysis
FMECAw	Weighted Failure Modes, Effects, and Criticality Analysis
FMECAmc	Multi-Criteria Failure Modes, Effects, and Criticality Analysis
HP	High Pressure
MCC	Main Control Cabinet
MCDA	Multi-Criteria Decision Analysis
MCDM	Multiple Criteria Decision Making
NF	Norme Française
NPSH	Net Positive Suction Head
O	Occurrence
PLC	Programmable Logic Controller
RCA	Root Cause Analysis
RO	Reverse Osmosis
RPN	Risk Priority Number
RPNct	Cost-Based Risk Priority Number
RPNmc	Multi-Criteria Risk Priority Number
RPNw	Weighted Risk Priority Number
S	Severity
SDI	Silt Density Index
TBF	Time Between Failures
TDS	Total Dissolved Solids
WPM	Weighted Product Method
WSM	Weighted Sum Method
H	Efficiency

General Introduction

General Introduction

Water treatment and desalination plants play a vital role in providing potable water, especially in regions suffering from limited water resources. The efficiency and continuity of these industrial systems largely depend on the reliability of the equipment used, particularly pumps, which are considered essential components in water transportation and reverse osmosis processes. Any failure affecting these systems may lead to operational interruptions, increased maintenance costs, and reduced performance efficiency.

Among the various types of pumps used in industrial applications, high-pressure centrifugal pumps are widely employed in water treatment and desalination plants due to their ability to provide the pressure required for reverse osmosis operations. However, these pumps are exposed to several types of failures such as cavitation, vibration, overheating, bearing damage, and sealing problems, which may negatively affect system reliability and operational safety[1].

To improve maintenance efficiency and reduce the impact of failures, industries increasingly rely on scientific methods for failure analysis and risk assessment. One of the most widely used methods is Failure Modes, Effects, and Criticality Analysis (FMECA), which allows the identification and prioritization of potential failures according to occurrence, severity, and detectability criteria. Nevertheless, the traditional Risk Priority Number (RPN) approach has certain limitations, mainly because it assigns equal importance to all evaluation criteria and may produce identical values for different failure modes.

In this context, this study aims to improve the FMECA methodology by integrating the Analytic Hierarchy Process (AHP) to determine the relative weights of the evaluation criteria, in addition to introducing maintenance cost as an extra criterion within a multicriteria model. The objective is to obtain a more accurate and realistic prioritization of failures and to support more effective maintenance decision-making [27].

The proposed methods were applied to a high-pressure pump operating in the Ifri Gara water treatment station in order to identify the most critical failure modes, improve maintenance planning, and enhance system reliability and operational performance.

This dissertation is organized into three main chapters. The first chapter presents a theoretical study on the station, centrifugal pumps, and water treatment processes. The second chapter introduces maintenance fundamentals, failure analysis, FMECA, and the AHP method. Finally, the third chapter focuses on the practical application of the proposed approaches and the analysis of the obtained results.

Chapter 1

I. Theoretical Study of the Ifri Gara Station and Centrifugal Pumps

I.1 Introduction

This chapter presents the Ifri Gara Station and its role in the treatment and desalination of groundwater for drinking water production using reverse osmosis technology. It describes the different stages of the treatment process, from raw water supply to the production of potable water, as well as the main equipment involved in the system operation.

The chapter also introduces pumps, particularly centrifugal pumps, which are considered essential components in water treatment and desalination plants. Their definitions, classifications, operating principles, components, characteristics, advantages, disadvantages, and applications are discussed in order to better understand their importance in ensuring efficient plant operation and water circulation throughout the treatment process.

I.2 Presentation of the Ifri Gara Station (Algerian Water)

I.2.1 Description of the station

The IFRI GARA Station is situated inside the IFRI GARA complex and has a total area of 9,397 square meters. The construction of the station started on January 1st, 2021. The station is intended for the desalination and demineralization of groundwater to produce drinking water. The station is currently running at 75% of its total treatment capacity with a desalinated water flow rate of 328 m³/hour using reverse osmosis technology, which is equivalent to 7875 m³/day. The treatment process also produces a wastewater flow of 110 m³/hour, in addition to a service water flow used for plant operation and maintenance of 37 m³/hour. [1].

Figure 0-1 : Ifri Gara Station[2].

The station receives raw water from four wells: Ifri 1, Ifri 2, Celis, and Customs. The rate of water flow from each of the wells is regulated by an electromagnetic flow meter fixed before the raw water tank. The water flow from each of the wells is also manually controlled by adjusting its valves[1].

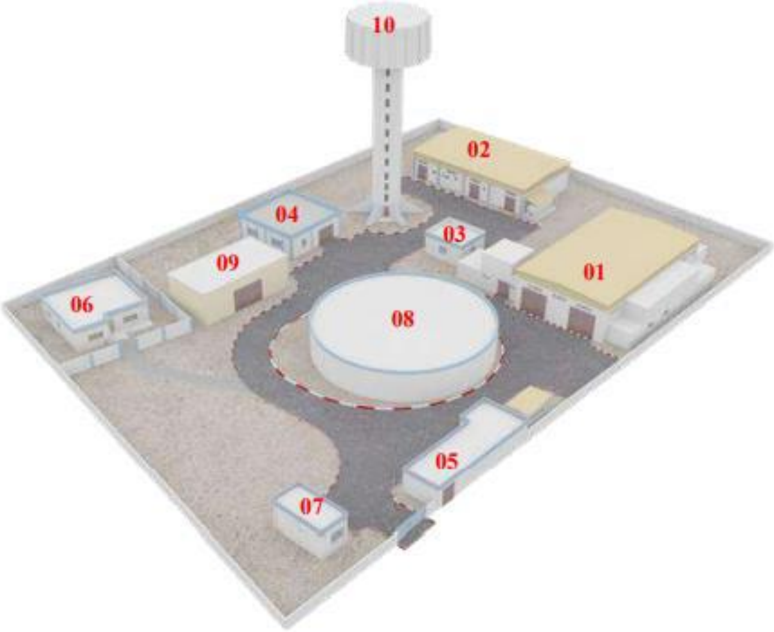

Figure 0-2 :3D view of the IFRI GARA S5 complex [3].

1. Treatment Building
2. Chlorination Building
3. Analysis Laboratory
4. Energy Workshop
5. Energy Room
6. Staff Housing
7. Guard Post
8. Water Storage Tank (existing structure)
9. Pumping Station (existing structure)
10. Water Tower (existing structure)

I.2.2 Description of the treatment

I.2.2.1 Treatment process chain

The main components of the salt (semi-salt) water treatment chain are as follows:

- ✓ Raw water basin.
- ✓ Prepare and dose calcium hypochlorite or sodium hypochlorite for primary chlorination when needed.
- ✓ Water preparation before sand filtration (pH reduction and sintering).
- ✓ Sand filter feed pumps.
- ✓ Sand filters.

- ✓ Filtered water basin.
- ✓ Low pressure feed pumps.
- ✓ Dechlorinate filtered water when needed.
- ✓ Continuous doses of an anti-settling agent (Antiscalant).
- ✓ Periodic dosing of a biocide as needed.
- ✓ Cartridge filters.
- ✓ High pressure feed pumps.
- ✓ Two-stage reverse osmosis unit.
- ✓ Reverse osmosis desalinated water basin.
- ✓ Make the water potable through final disinfection (subsequent chlorination) and lime milk dosing.

I.2.2.2 Process description

- ✓ **Supply from Wells**

Raw water is drawn from the existing wells and then pumped into the raw water basin.

- ✓ **Sand Filter Feed Pumps**

The pumping station consists of three pumps, one of which is on standby, to supply the sand filters from the raw water tank. The station can be operated in either manual or automatic mode.

Manual mode: Start and stop are controlled via the buttons on the Main Control Cabinet (MCC).

Automatic mode: The station is controlled by a Programmable Logic Controller (PLC), with automatic mode activated from the supervisory system, allowing start and stop commands to be executed directly from the supervisor.

- ✓ **Pre-treatment-sand filters**

a) Filtration: The filters are horizontal pressure-type, made of steel and coated with food-grade Rexyplast. The filter bed consists of a layer of fine sand to retain suspended solids and rests on a metal floor equipped with distribution nozzles.

To ensure better water distribution during operation and effective backwash collection, a channel runs along the entire length of the filter. The adopted filtration rate is 9 m^3/h during normal sand filter operation, ensuring a sufficiently low Silt Density Index (SDI) for feeding the reverse osmosis system[3].

Figure 0-3 : Sand filtration tanks

b) Filter cleaning

The filter washing process is an automated or manual sequence controlled via the PLC, utilizing filtered water for backwashing. The strategy relies on a dual-media cleaning approach (air + water): it begins with depressurization and water level adjustment, followed by air scouring and pulsed water injections to loosen debris and release trapped air. The cycle concludes with a high-rate backwash and final rinse before returning the filter to service. Crucially, the duration of each phase is calibrated during the trial and semi-industrial phases based on the clogging rate and water temperature.

- ✓ **Cartridge filters and discharge valve**

To prevent large particles or fine sand from entering the membrane system, replaceable cartridge filters are installed. The cartridges are made of polypropylene wire wound helically, with a nominal retention rating of5 microns.

Downstream of the microfilters, measurement points are provided for key operating parameterssuch as redox potential, pH, conductivity, turbidity, temperature, and SDI.

If the raw water quality is outside the required limits for membrane operation, a discharge valve located downstream of the microfilter can be opened to divert water to waste until the quality is restored.

- ✓ **Reverse Osmosis System**

Downstream of the cartridge filters, the pretreated water is pressurized by a high-pressure pump to supplythe dedicated reverse osmosis (RO) train.

Each train consists of pressurized vessels containing six spiral-wound membranes made of composite polyamide.

The configuration of a reverse osmosis train varies according to the salt content of the raw water.

Indeed, as water conductivity increases, the recovery rate must be reduced in order to ensure satisfactory permeate quality at the outlet[3].

The following parameters were taken into account for the design and sizing of the reverse osmosis trains:

- ✓ Total Dissolved Solids (TDS) of the raw water
- ✓ Total Dissolved Solids (TDS) of the permeate
- ✓ Total Dissolved Solids (TDS) of the concentrate
- ✓ Membrane flux
- ✓ Membrane wear rate

Figure 0-4 : Reverse Osmosis System [4].

- ✓ **Cleaning Station**

This system is used for the cleaning and disinfection of the membranes. The cleaning solution is prepared in a dedicated tank and then recirculated by the cleaning pumps. It flows through the cleaning station microfilter and subsequently through the reverse osmosis units.

The cleaning operation is manually initiated according to operational requirements and the condition of the membranes.

I.3 Definition of a Pump:

The term pump, derived from the Italian word *"pompa"*, refers to all hydraulic machines used to move liquids from a low-pressure area to a high-pressure area. Its operation consists of creating a pressure difference between the suction zone and the discharge zone through the pump's active element (piston, impeller, etc.). From a physical perspective, the pump converts mechanical energy into hydraulic energy[5].

In a hydraulic circuit, the pump plays an equally important role, similar to the role of the heart in the human body.

The pump allows the hydraulic fluid to circulate through pipes, moving loads using cylinders or hydraulic motors.

The pump plays a key role because it provides the energy in the hydraulic circuit. The increase in the pressure of the fluid conveyed by the pump occurs as a result of transforming the mechanical energy supplied by the motor driving the pump into hydraulic energy gained by the fluid between the pump's inlet and outlet[6].

In water desalination plants operated by the Algerian Water Company, pumps play a crucial role in ensuring water flow through the various treatment stages, particularly in reverse osmosis units, where they provide the high pressure required to force saline water through the membranes and separate salts and impurities. Therefore, pumps are essential components for operational stability and for maintaining the quality of the produced water, making their understanding, operation, and maintenance critically important to achieving optimal plant performance.

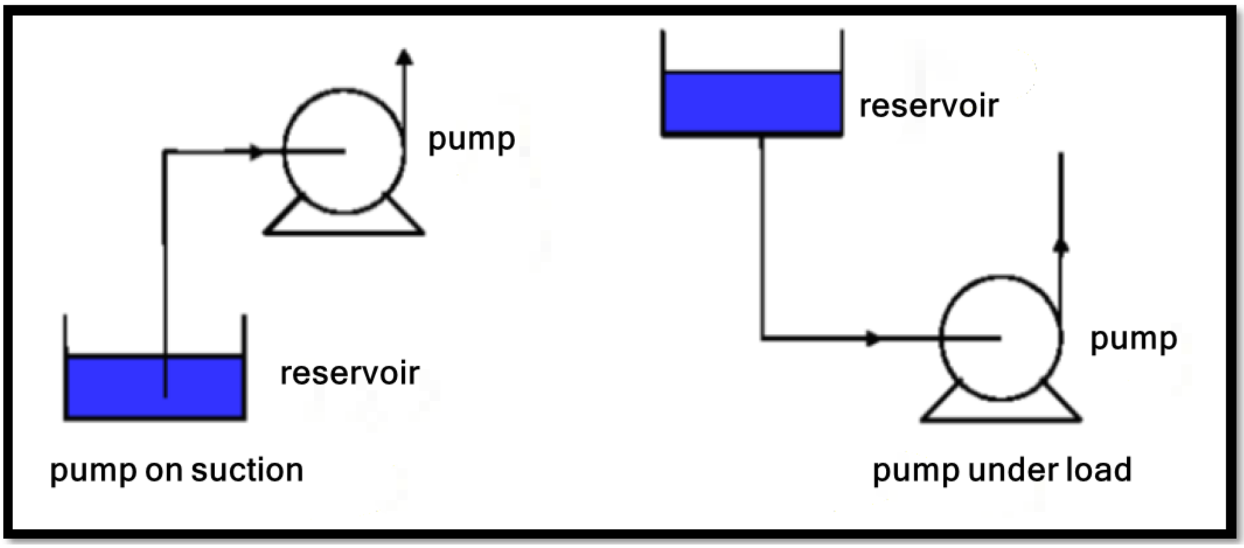

Figure 0-5 : Installation of a Pump on Suction and Under Load

I.4 Pump Classification:

In general, pumps are classified into two main families, based on the method of transporting the fluid and the nature of their operation:

- Dynamic
- Positive displacement

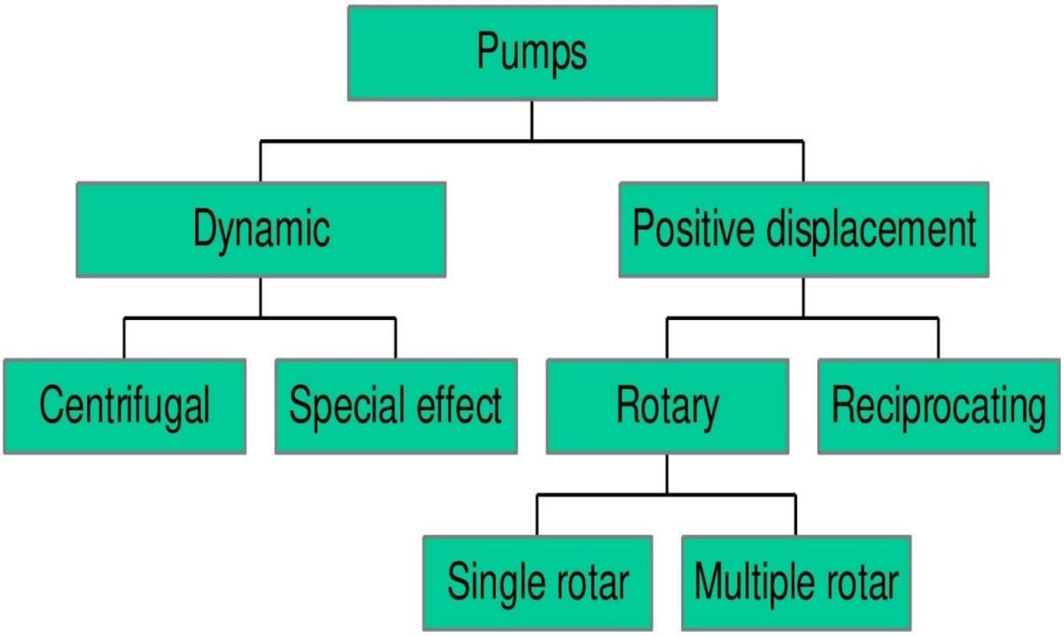

Figure 0-6 : Pump Classification

I.4.1 Centrifugal Pumps

A centrifugal pump is defined as an open system within which a centrifugal force field is generated, and it may be regarded as a passage or a conduit allowing the flow of fluid. The operating principle of this type of pump is not based on transporting the fluid in buckets or on the time variation of a confined volume, as is the case with positive displacement pumps. Instead, the fluid is imparted kinetic energy and set into continuous motion under the effect of rotational forces, reaching equilibrium within a centrifugal force field without being pushed by a solid boundary.

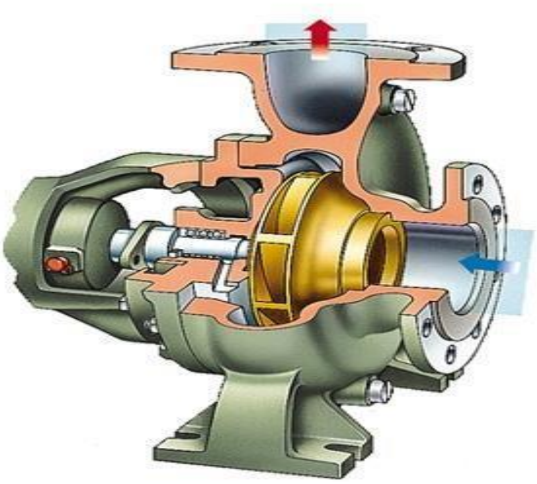

Figure 0-7 :Centrifugal Pump

I.4.1.1 Centrifugal Pump Components

- **Impeller (the wheel)**

The impeller is the essential component of a centrifugal pump. It consists of a hub mounted on a shaft and equipped with blades that rotate inside two casings forming the pump body. The blades are uniformly spaced in the angular direction, and their number may vary depending on the pump design. They are generally backward-inclined, meaning that the trailing edge of each blade lags behind the leading edge in the direction of rotation. The blades may be attached to one or both side discs; accordingly, impellers are classified as open, semi-open, or closed types.

- **Casing (Volute)**

The volute is a stationary component of the pump that directs the fluid from the pump inlet to the impeller, ensuring the appropriate velocity and flow direction.

- In single-stage pumps, the volute is generally a simple pipe, either straight or bent, depending on the design.
- In multi-stage pumps, volutes are typically absent in the subsequent stages, except for the first stage, where the inlet volute is often shaped as a flat elbow. The fluid then flows from the discharge of one stage to the inlet of the next impeller through fixed elements equipped with blades, known as impeller channels.

- **Diffuser**

The diffuser is a stationary component of the pump that collects the fluid at the impeller outlet and directs it to the pump's discharge section at the desired velocity. This process is accompanied by a partial conversion of the fluid's kinetic energy at the impeller exit into pressure energy.

- ✓ In single-stage pumps, the diffuser typically consists of an annular passage surrounding the impeller and opening into the pump's discharge section. The walls of the diffuser may be parallel or diverging depending on the design, and it may include blades in some cases. In some designs, the diffuser may be reduced or even absent, with the impeller discharging directly into the volute.
- ✓ In multi-stage pumps, each impeller is usually followed directly by the final volute[5].

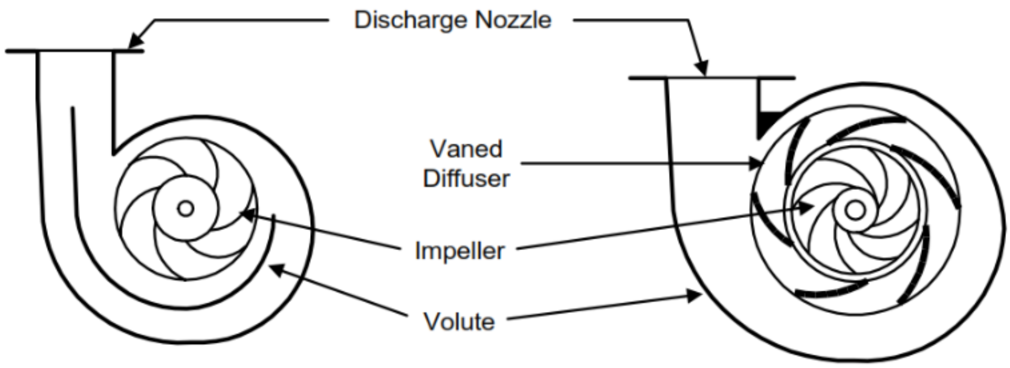

Figure 0-8 :Constitution of a pump [7].

I.4.1.2 Principle of Operation of a Centrifugal Pump

The operation can be divided into three stages:

- **Aspiration:**

The liquid is drawn toward the center of the rotor through an opening called the distributor, whose role is to guide the fluid from the suction pipe to the inlet section of the rotor. When the pump is primed, meaning it is completely filled with liquid, the velocity of the fluid entering the impeller increases, which causes a decrease in pressure at the impeller eye. This pressure drop creates suction and ensures continuous priming.

- **Acceleration:**

The rotation of the impeller increases the velocity of the fluid, while the centrifugal force pushes it toward the periphery, resulting in an increase in pressure. The impeller blades are often curved and inclined backward relative to the direction of rotation, but this design is not mandatory.

- **Discharge (Refoulement):**

In the expansion area at the pump outlet, which acts like a diffuser, the fluid velocity decreases while its pressure increases, as the fluid’s kinetic energy is converted into pressure energy[8].

I.4.1.3 Types of Centrifugal Pumps

A) Vertical Centrifugal Pumps

A vertical centrifugal pump consists of an impeller that rotates around a vertical shaft. The liquid enters the pump along the shaft, and the centrifugal force pushes it toward the periphery of the turbine, giving it high kinetic energy.

The fluid is then discharged through the outlet port. These pumps are especially used when the suction height is relatively low.

Their main applications include: chemical industries, industrial processes, electroplating, printed circuit board manufacturing, and water and wastewater treatment.

Figure 0-9. Vertical Centrifugal Pumps

B) Horizontal Centrifugal Pumps

It is a pump with a horizontal shaft, and it can be found in single-stage or multi-stage configurations[9].

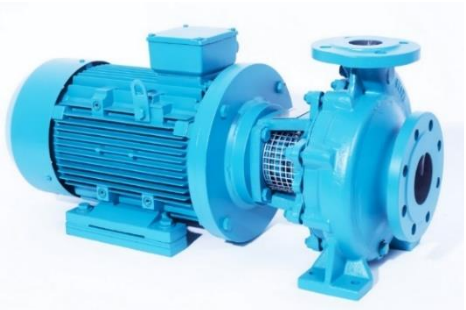

Figure 0-10 :Horizontal Centrifugal Pumps

I.4.1.4 Classification of Centrifugal Pumps

Centrifugal pumps are classified according to their operating principle.

a) Shaft arrangement :

- Horizontal shaft pumps
- Vertical shaft pumps (submersible pumps)

b) Number of impellers :

- The number of impellers corresponds to the number of stages.

c) Impeller shape :

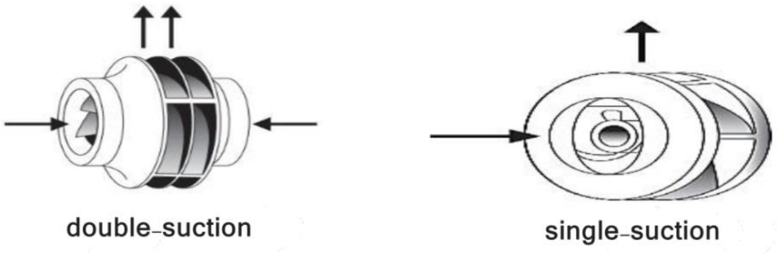

Figure 0-11 :Double-suction impeller and single-suction impeller

d) Generated pressure

- Low pressure

- High pressure

e) Coupling method

- By chain
- By gear
- By flange
- By belt

f) Drive method

- By electric motor
- By diesel or gasoline engine
- By steam or gas turbine

g) Type of casing

- Volute
- Diffuser

h) Application/Use

- Standard pump
- Slurry pump
- Acid pump
- Fuel oil and gasoline pump[10].

I.4.1.5 Characteristics

➢ Efficiency

The efficiency of a pump is the ratio of the hydraulic power delivered to the fluid to the mechanical power supplied to the pump. It varies with the flow rate and is typically shown as a curve provided by the manufacturer. Efficiency allows calculation of the shaft power when the hydraulic power is known[11].

The best efficiency point determines the nominal flow rate, at which the nominal head and nominal power are achieved.

Typical maximum efficiency values are:

- 70% for pumps running at 3000 rpm
- 80% for pumps running at 1500 rpm
- 80% for high-power pumps
- 50–60% for small pumps

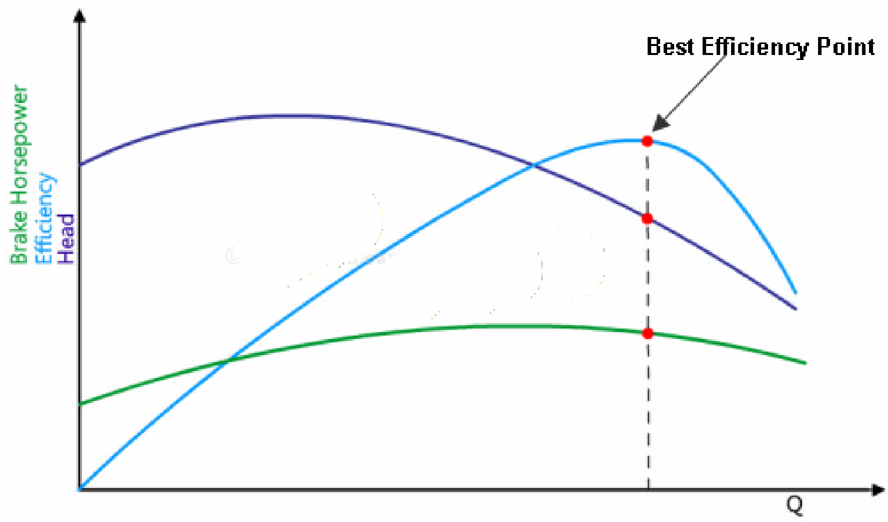

Figure 0-12 :Change in efficiency and pump shaft power input with flow rate

- Power

The shaft power is a pump characteristic that allows determining the appropriate driver or motor. This power is calculated based on the head (H), efficiency (η), and fluid density (ρ) for a given flow rate. $P_a = \frac{P \times H}{\eta} = \frac{H \times Q \times d}{367 \times \eta}$……………………………………**(I-1)**

P:power in KW / H: Head in meters (m) / Q: Flow rate in (m^3/h) / d: density

η: pump efficiency

The power is proportional to the density of the conveyed liquid. The manufacturer sometimes plots the power curve for water (d = 1) and calculates it for another value. For centrifugal pumps, the shaft power generally increases with flow rate. When the flow is zero, for example when the discharge valve is closed, the power is between 40% and 60% of the nominal power.

In this case, all the power is dissipated as heat in the liquid, with the risk of the liquid vaporizing if it is near its boiling point[11].

- **Required NPSH**

The pump manufacturer must also provide the NPSH curve as a function of flow rate. This curve is usually plotted between 40–50% and 100–110% of the nominal flow.

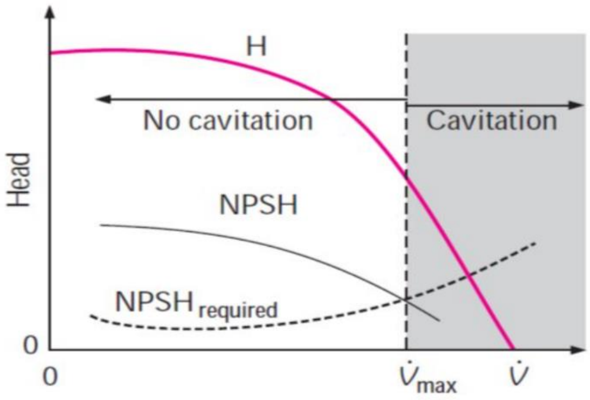

Figure 0-13NPSH Available and NPSH Required as a Function of Flow Rate

The NPSH value at nominal flow is approximately:

- 3 to 4 meters for process pumps running at3000 rpm.
- 2 to 2.5 meters for pumps running at 1500 rpm**.**
- Without specific equipment to reduce NPSH, high-speed pumps can have NPSH values reaching 10 meters**.**

In general, the higher the rotational speed or the higher the velocity of the liquid entering the impeller, the higher the NPSH[11]**.**

I.4.1.6 Cavitation

Cavitation is a term used to describe the phenomenon that occurs in a pump when the NPSH (Net Positive Suction Head) is insufficient. The liquid pressure is reduced to a value equal to or lower than its vapor pressure where small bubbles or vapor pockets begin to form.

The production of cavities due to bubbles or vapor pockets in the flowing liquid generates very violent shocks and rapid, dramatic mechanical abrasion that can very quickly destroy the pump components (impeller and diffuser).

The only way to prevent the undesirable effects of cavitation is to ensure that the NPSH available in the system is higher than the NPSH required by the pump[9].

Figure 0-14 :Cavitation damage to the components of a centrifugal pump

I.4.1.7 Bearing and seal oil cooling system

An oil tapping taken from the pump discharge is directed to a water-cooled heat exchanger, where the oil enters at a temperature of **124 °C** and leaves at approximately **64 °C**. The cooled oil is subsequently used to ensure the proper cooling of the pump mechanical seals. In addition, three cooling water lines are provided in order to guarantee the efficient thermal regulation of the pump components. These lines ensure :

- ✓ The cooling of the oil used for the **mechanical seal system**.
- ✓ The cooling of the **bearing located on the pump side**.
- ✓ The cooling of the **bearing located on the coupling side**.

This cooling system plays a crucial role in maintaining the reliability and safe operation of the pump by preventing excessive temperatures that could lead to premature wear or damage of critical components.

I.4.1.8 Advantages of centrifugal pump

- Weight, size, initial cost, and the installing cost are lower than PD pumps with the same hydraulic conditions.
- They can be fixed to a high-speed driving mechanism.
- It can handle liquids containing catalysts, and dirt solids.
- The cost of production, therefore the price is low.
- Variable-capacity control over operating range at a constant speed[12].

I.4.1.9 Disadvantages of centrifugal pump

- Additional priming is required.
- Develops limited head over operating range at a constant speed
- Cannot deal with high viscous fluid.
- Low to moderate efficiencies

I.4.1.10 Applications of centrifugal pump

- Power Plants
- Refineries, Chemical, and Petrochemical Plants.
- Oil and Gas Industries.
- Chemical and Mining Industry.
- Pharmaceutical Industries.
- Farming
- Water Treatment Plants

- Fire Protection Industries, etc[12].

I.4.2 Explanation of the Studied Pump and Its Role

The studied equipment is a High-Pressure Centrifugal Pump used in the reverse osmosis unit of the Ifri Gara water treatment station.

This pump plays a fundamental role in the desalination and water treatment process because it provides the high hydraulic pressure required to force water through the reverse osmosis membranes. These membranes separate salts, impurities, and dissolved particles from the water in order to produce potable water.

Figure 0-15High Pressure Pump (HP)

The pump operates according to the centrifugal principle. The electric motor drives the impeller at high rotational speed, which increases the kinetic energy of the water and converts it into pressure energy. As a result, the water is transported from the suction side to the discharge side under high pressure.

The studied pump consists mainly of:

- ✓ Impeller,
- ✓ Shaft,
- ✓ Bearings,
- ✓ Mechanical seal,
- ✓ Volute casing,
- ✓ Coupling system,
- ✓ Cooling and lubrication system.

During operation, the pump is exposed to several mechanical and hydraulic stresses such as vibration, cavitation, overheating, bearing wear, seal leakage, and misalignment. These failures may lead to production shutdowns, reduced efficiency, increased maintenance costs, and damage to the reverse osmosis system.

For this reason, the high-pressure pump was selected as the subject of this study in order to analyze its critical failure modes and improve maintenance decision-making using the FMECA, AHP, and multicriteria approaches.

The reliability of this pump directly affects:

- The continuity of water production,
- The operational stability of the station,
- The quality of treated water,
- And the overall maintenance cost of the installation.

Therefore, ensuring the proper operation and maintenance of the high-pressure pump is essential for improving the performance and reliability of the water treatment station

I.5 Conclusion

This chapter provided a detailed overview of the Ifri Gara Station and the different stages involved in the water treatment and desalination process using reverse osmosis technology. It also highlighted the importance of pumps, especially centrifugal pumps, in maintaining the operation and efficiency of the treatment system.

Furthermore, the chapter discussed the classification, operating principle, main components, characteristics, advantages, disadvantages, and applications of centrifugal pumps, in addition to important operational aspects such as cavitation and cooling systems.

Chapter II

II. FUNDAMENTALS OF MAINTENANCE

II.1 Introduction

Since ancient times, humans have felt the need to maintain and repair their equipment whenever failures occur. However, the term maintenance only began to be widely used in the industrial field during the 1950s. With the development of modern industry, the maintenance of production equipment has become an essential factor in improving factory productivity and ensuring product quality. One of the main tasks of maintenance personnel is to identify which failures should be treated as a priority, since some failures may have only a limited impact in terms of consequences or costs. Therefore, the primary objective of the maintenance function is to ensure the highest possible availability of production facilities while minimizing downtime in an economically efficient way[13].

In this chapter, general concepts related to maintenance will be presented. In addition, several methods used for failure analysis and decision-making will be discussed, such as Failure Analysis, the FMECA method, Multi-Criteria Decision-Making (MCDM) approaches.

II.2 Maintenance

II.2.1 Maintenance Definition

According to AFNOR (NF X 60-010):Maintenance is the set of technical, administrative, and management actions during the life cycle of an asset, intended to maintain or restore it to a state in which it can perform its required function [14].

This definition includes the main concepts of maintenance, which are:

- Maintain: Refers to the concept of prevention for a system that is in operation.
- Restore: Refers to the concept of correction after a loss of function has occurred.
- Specified state or determined service: Implies defining in advance the objective to be achieved, with a quantitative specification of the required performance levels.
- Optimal cost: Refers to carrying out all operations with the aim of achieving maximum efficiency while minimizing costs[15].

II.2.2 Maintenance History

Before World War II, maintenance was generally viewed as an additional cost to the plant that did not add value to the final product. As a result, maintenance at that time was largely limited to repairing equipment only when it broke down, as this was considered the most economical option. However, with the advancement of engineering and scientific technology during and after the war, new types of maintenance were developed that were more effective and cost-efficient, such as preventive maintenance. Maintenance was also classified during this period as a function of the production system.

Today, with growing awareness of issues such as environmental safety and product and service quality, maintenance has become one of the most critical functions contributing to industrial success. Leading global companies continuously implement well-organized maintenance programs to ensure competitiveness in the international market[16].

II.2.3 Maintenance Objectives

The main objectives that the maintenance function must set are:

- Enhancing Equipment Reliability:

Preventive maintenance requires analyzing equipment behavior to optimize maintenance activities and reduce the occurrence of failures, sometimes even eliminating certain types entirely.

- Ensuring Product Quality:

Machines are regularly monitored to detect early signs of failure and to ensure that operating and adjustment parameters are met. Monitoring clearances, such as vibrations, and machine geometry helps prevent operational problems, ensuring product quality and minimizing scrap.

- Improving Work Scheduling:

Maintenance interventions must be coordinated with the production department, especially during planned machine downtime. Effective collaboration ensures that maintenance tasks are carried out smoothly while respecting production requirements.

- Ensuring Human Safety:

Planning preventive maintenance requires not only following the schedule but also considering safety measures to prevent accidents or unforeseen hazards during maintenance activities.

- Improving Inventory Management:

Preventive maintenance allows better planning of component and spare part replacements, which facilitates inventory management and prevents unnecessary stockpiling by ordering parts only when needed [17].

II.2.4 Maintenance classification

According to the European Standard EN 13306, (as shown in Figure II.1), preventive maintenance is classified into two main categories: Condition-Based Maintenance and Pre-Determined Maintenance (CEN, 2001)[18].

Corrective maintenance, on the other hand, is divided into two types: Deferred Maintenance and Immediate Maintenance.

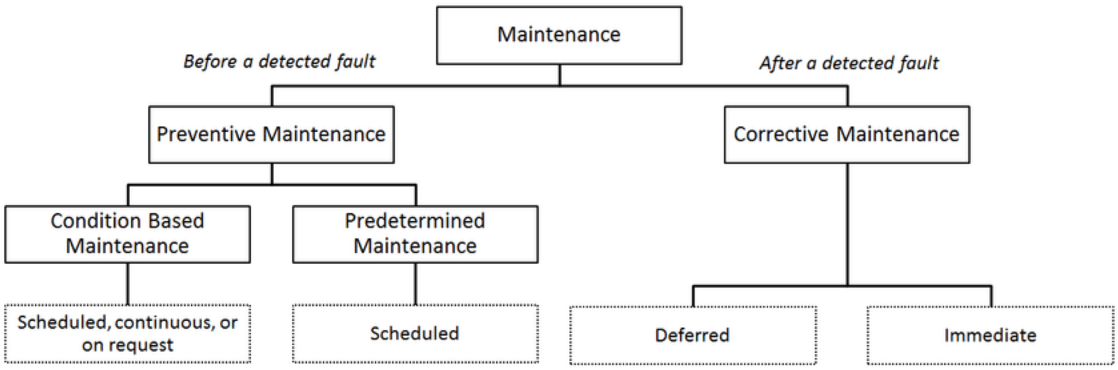

Figure II-1 :Maintenance types by CEN (2001)

II.2.4.1 Preventive maintenance

Defined as "maintenance carried out at predetermined intervals or according to prescribedcriteria and intended to reduce the probability of failure or the degradation of the functioning of an item "[19].

a) Condition-based maintenance

Is defined as "preventive maintenance which include a combination of condition monitoring and/or inspection and/or testing, analysis and the ensuing maintenance actions"[19].

b) Predetermined maintenance

Defined as "preventive maintenance carried out in accordance with established intervals of time or number of units of use but without previous condition investigation".

II.2.4.2 Corrective maintenance

Defined as "maintenance carried out after fault recognition and intended to put an item into astate in which it can perform a required function".

a) Deferred

defined as "corrective maintenance which is not immediately carried out after a fault detection but is delayed in accordance with given rules"[19].

b) Immediate

Defined as "corrective maintenance that is carried out without delay after a fault has been detected to avoid unacceptable consequences"[19].

II.2.5 Maintenance Levels

According to the AFNOR standard (NF X60-011), the maintenance and operation of assets are carried out through a variety of activities, some routine and repetitive, and others occasional or exceptional. These activities have traditionally been classified into five maintenance levels.

This classification helps in systematically prioritizing maintenance tasks, which can be based on several criteria, including:

Defining who is responsible for each activity at each maintenance level:

- ✓ Production personnel
- ✓ Maintenance personnel, taking into account the qualifications of the person performing the task
- ✓ Company personnelor subcontractors
- ✓ A combination of the three[20].

Table II-1Maintenance Levels

Level	Task Complexity	Required Skill	Tools Used	Location	Example
1	Simple Adjustements	Technician or Operator	Basic tools (brush ,gauge	On-site	Lubrication
2	Low-Complexity Actions	Qualified Technician	Standard portable tools (wrenches, pliers)	On-site	Belt replacement
3	Complex Actions	Specialized Technician	Specific tools (multimeter)	On-site or Workshop	Distributor repair
4	High-Importance Actions	Specialized Technician or team with superviser	Collective and specific tools	Specialized Workshop	Transformer repair
5	Highly Complex operations	Construction Team	Manufacturer-specific tools	External Workshop	Machine overhaul

II.3 Failure Analysis

II.3.1 Definition

Failure Analysis is the process of collecting and analyzing failure data in order to identify the root cause of a malfunction or breakdown in equipment or systems. The results of this analysis are used to improve the design of components and machines, adjust maintenance schedules, and enhance maintenance procedures, thereby increasing the reliability and performance of industrial systems.

Failure analysis is usually conducted after a failure has occurred and is considered an important part of the Root Cause Analysis (RCA) process. However, it can also be used to identify factors that may lead to potential failures and to implement appropriate preventive measures to avoid their occurrence.

II.3.2 Importance of Failure Analysis

In today's rapidly evolving industrial and technological landscape, increasing efficiency, productivity, and cost reduction has become essential, while ensuring equipment safety and reliability.

Implementing failure analysis is therefore crucial to systematically investigate failures, identify root causes, and prevent recurrence. This enhances the reliability and operational efficiency of industrial systems.

Failure analysis also ensures the reliability of components from suppliers before integration into the final product, helping industries reduce downtime, lower costs, improve product quality, and maintain customer trust.

II.3.3 Failure Analysis Techniques

Many failure analysis techniques are notable for their effectiveness and applicability across various industrial sectors. Among these techniques, Root Cause Analysis (RCA) stands out in particular. RCA is a systematic process for identifying the fundamental causes of failures, ensuring that solutions address the underlying problem rather than just the symptoms. This approach often involves techniques such as the “5 Whys” method, Fishbone Diagrams, and Failure Modes and Effects Analysis (FMEA) to systematically map out potential causes and their impacts[21].

II.3.3.1 The Five Whys Technique

When trying to solve a problem, it is helpful to start by looking at the end result, reflect on what caused it, and ask **"Why?"** five times in succession for each answer. This simple yet often effective approach encourages deep thinking and helps uncover the root causes of problems. It can also be quickly adapted to a wide range of situations.[22]

The Five Whys technique is closely linked to the principle of systematic problem solving; without applying this principle, the technique becomes merely a formal procedure that may not yield real results. To use it effectively, three key elements should be observed:

1. Accurately and completely define the problem.
2. Be completely honest when answering the questions.

3. Have the determination to get to the root cause and resolve the problem[23].

- **Process**

The Five Whys technique works best when applied by a team. The main steps are:

1. Assemble the team and define the problem clearly, and determine if additional people are needed.
2. Ask the first "Why?" about the problem and record all plausible answers on a flip chart, whiteboard, or index cards.
3. Ask four more successive "Whys" for each answer, following up on all reasonable responses until the root cause is identified.
4. Identify systemic causes from the final answers, discuss them, and confirm the most likely root cause. Review the findings with others to ensure the analysis is logical.
5. Develop corrective actions to remove the root cause, leveraging team input for planning and implementation[23].

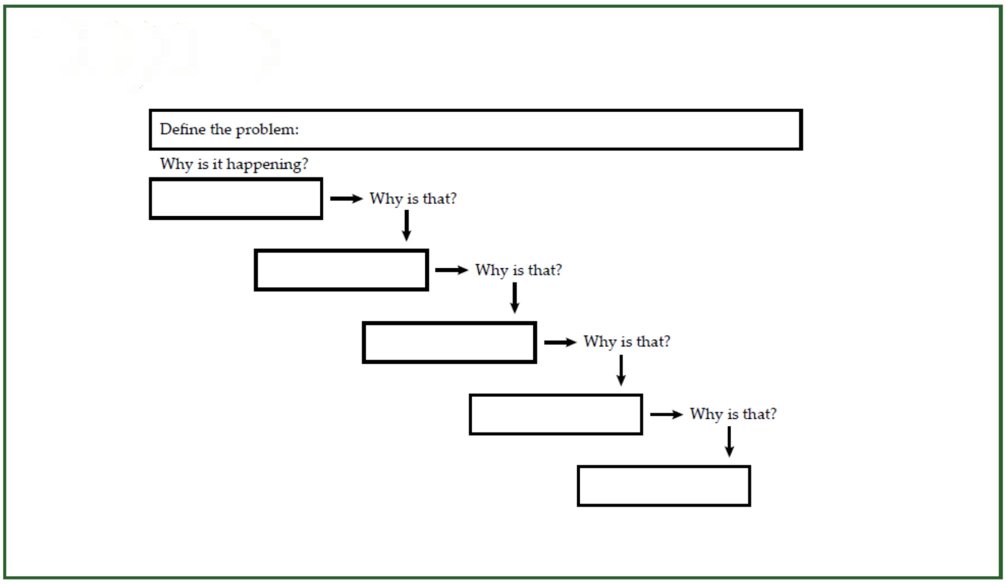

Figure II-2 :Five Whys Worksheet

II.3.3.2 Failure Modes, Effects, and Criticality Analysis (FMECA)

FMECA is a qualitative and inductive method aimed at identifying the risks of potential failures contained in a preliminary design of a product or system, regardless of the technologies used, in order to eliminate or control them from the outset. It is standardized by the AFNOR: standard X 60-510 of December 1986[24].

II.3.3.2.1 Objectives of FMECA

As an inductive approach, FMECA is first used to identify failures that produce effects capable of affecting a system and its operation. In addition, thanks to the concept of criticality, this method makes it possible to rank failure modes by priority in order to control them. Therefore, the main objective of this analysis is to ensure the dependability of operation (safety, reliability, maintainability, and availability) of a product, a system, or a production facility.

II.3.3.2.2 Principle of the Method

Since the objective of this approach is to develop an effective preventive action plan, it is essential that the team working on FMECA possesses a thorough and in-depth understanding of the system under study. This level of knowledge enables a clear and systematic analysis of its components and functioning, and allows the team to accurately answer the four fundamental questions on which this method is based.

Table II-2Four Basic Questions of FMECA

Failure Modes	Possible Effects	Possible Causes	Monitoring Plans
What could go wrong ?	What could be the effects ?	What could be the causes ?	How can it be detected ?

By answering these questions, the Failure Modes and Effects Analysis (FMEA) team aims to identify potential failure modes in the equipment, rank them according to their level of risk, and determine their effects and causes on the essential functions of the system.

FMECA is not an end in itself, but rather a tool used to assess and quantify the level of risk associated with different failures, based on three key criteria: occurrence, severity, and detectability.

If the evaluated level of risk is deemed unacceptable, the team proceeds to develop corrective and/or preventive maintenance plans to improve the system by reducing the risk level. This can be achieved by minimizing the severity of the failure effects, reducing their occurrence, or enhancing their detectability.

II.3.3.2.3 The FMECA table

Table II-3FMECA table

Steps in the process	Failure Mode	Failure Causes	Failure Effects	Occurrence (1-4)	Detection (1-4)	Severity (1-4)	Risk Priority Number (RPN)	Action to Reduce Occurrence of Failure

II.3.3.2.4 Quantitative Analysis in (FMECA)

The concept of **criticality** (also called the **Risk Priority Number – RPN**) is evaluated based on three main factors:

- ✓ **O (Occurrence):** probability of failure occurrence
- ✓ **S (Severity):** seriousness of the consequences
- ✓ **D (Detection):** probability of not detecting the failure.

The Risk Priority Number is calculated as:

$$RPN = O \times S \times D \quad \textbf{(II-1)}$$

This formulation is the standard and widely used notation in FMECA, where a higher RPN indicates a higher-risk failure mode[25].

II.3.3.3 Multiple Criteria Decision Making (MCDM)

Multiple Criteria Decision Making (MCDM) is a decision-support approach used to evaluate and rank alternatives based on several criteria simultaneously. Unlike traditional decision-making methods that rely on a single factor, MCDM considers multiple quantitative and qualitative criteria in order to obtain a more comprehensive and reliable assessment.

MCDM techniques are widely applied in engineering, maintenance management, risk analysis, and industrial systems, where decision-makers must select the best alternative while considering different and often conflicting criteria such as cost, reliability, safety, performance, and maintenance requirements.

In maintenance engineering and FMECA analysis, MCDM methods are particularly useful for prioritizing failure modes by integrating additional criteria beyond the conventional factors of occurrence (O), severity (S), and detection (D). For example, maintenance cost, operational impact, downtime, or environmental consequences can be incorporated into the evaluation process to improve the accuracy of criticality assessment.

In the present study, the MCDM approach was employed to improve the prioritization of failure modes in the high-pressure pump system by integrating the maintenance cost criterion with the traditional FMECA parameters. This integration provided a more realistic and economically oriented evaluation of system criticality, leading to more effective maintenance planning and decision-making[26].

II.3.3.3.1 Purpose and Importance of MCDM

Multi-Criteria Decision Making (MCDM) is essential because real-world decision problems often involve multiple, conflicting criteria that cannot be evaluated using a single factor. It provides a structured and systematic approach to compare alternatives by considering all relevant aspects simultaneously, such as cost, quality, time, and risk. MCDM helps decision-makers improve the accuracy and transparency of their choices, reduce subjectivity, and justify decisions based on logical evaluation. As a result, it is widely used in engineering, management, and industrial applications where complex decisions must be made efficiently and rationally.

II.3.3.3.2 Popular MCDM Methods

- ✓ Weighted Sum Method **(WSM):** Adds weighted scores to rank alternatives.
- ✓ Weighted Product Method (**WPM):** Multiplies weighted scores for proportional comparison.
- ✓ Analytic Hierarchy Process **(AHP):** Uses pairwise comparisons to prioritize alternatives.
- ✓ **TOPSIS**: Ranks alternatives based on closeness to the ideal solution.
- ✓ **PROMETHEE**: Ranks alternatives using preference functions and flows.
- ✓ **VIKOR:** Finds compromise solutions balancing overall utility and individual regret.

II.3.3.4 AHP Method (Analytic Hierarchy Process)

The Analytic Hierarchy Process (AHP) is one of the most widely used Multi-Criteria Decision-Making (MCDM) methods. It helps in understanding a problem and selecting a decision that aligns with the objectives of experts. Its strength lies in its general ease of understanding.

The AHP method first decomposes the original decision problem into a hierarchical structure that includes the decision goal, alternatives, criteria, and comparisons to determine the priorities of all elements.

The AHP method is carried out in four main steps to establish and rank all alternatives[27].

II.3.3.4.1 Structuring the Hierarchy

The first step is to break down the decision problem into a hierarchical structure with several levels:

- ✓ **Goal** (the main objective of the decision)
- ✓ **Criteria and sub-criteria** (factors influencing the decision)
- ✓ **Alternatives** (the options to choose from)

This step helps simplify complex problems by organizing them clearly.

II.3.3.4.2 Priority Calculation in AHP

In the Analytic Hierarchy Process (AHP), the second step focuses on determining the **priority (or weight**) of each element in the decision model. This includes two levels of évaluation :

- ✓ The importance of each criterion relative to the main goal
- ✓ The importance of each alternative relative to each criterion

The result of this process is a numerical value between 0 and 1, representing how significant each element is in the decision-making process. These values are called priority weights.

To obtain these priorities, AHP uses the pairwise comparison approach, where elements are compared two at a time. Decision-makers judge which element is more important and assign a score that reflects the strength of preference, typically using Saaty's scale (1 to 9).

This comparison process is repeated for all criteria and alternatives, forming structured comparison matrices. From these matrices, the priority values are derived mathematically through normalization and averaging techniques, resulting in a consistent priority vector that supports decision-making.

II.3.3.4.3 Consistency Check of the Pairwise Comparison Matrix

The third step involves verifying the consistency of the pairwise comparison matrices, which requires calculating the Consistency Index (CI).

This index is based on the principal eigenvalue of the matrix (λmax), where *n* represents the number of independent rows (or the size of the matrix).

If the decision-maker's judgments are perfectly consistent

$$CI = \frac{\lambda max - n}{n - 1} \text{....................................(II-2)}$$

II.3.3.4.4 Synthesis of Final Priorities

The final step of the AHP process consists of aggregating all local priority values to obtain the overall (global) priorities, which are then used to select the best alternative.

In complex decision-making problems, the goal is to identify the most suitable option among several alternatives evaluated under multiple criteria.

In this stage, the results derived from the pairwise comparisons are combined in a systematic way to generate the final ranking of alternatives. This aggregation process transforms local judgments into a comprehensive decision framework, enabling the selection of the optimal solution based on all considered criteria.[27].

II.4 Conclusion

In this chapter, a comprehensive overview of maintenance has been presented by discussing its fundamental definitions, main types, and its strategic role in ensuring system reliability and operational performance. In addition, failure analysis was highlighted as an essential approach for identifying the root causes of equipment breakdowns and supporting more effective maintenance decisions.

Moreover, key decision-support and analytical tools were introduced, particularly the AHP (Analytic Hierarchy Process) and FMECA (Failure Modes, Effects, and Criticality Analysis) methods. These approaches are widely used in maintenance engineering to structure complex decision problems, evaluate failure modes, prioritize risks, and support optimal decision-making based on multiple criteria.

Overall, this chapter emphasizes the importance of integrating both qualitative and quantitative techniques in maintenance management. The combination of AHP and FMECA provides a powerful framework for improving prioritization, enhancing risk assessment, and supporting more efficient maintenance planning. Consequently, this theoretical foundation prepares the ground for the following chapters, where these methods will be applied in a practical case study.

Chapter III

III. APPLICATION OF FMECA METHOD

III.1 Introduction

In this chapter, three risk assessment methods will be applied to the High Pressure Pump (HP), namely the traditional Risk Priority Number (RPN), the Weighted Risk Priority Number (RPNw), and the Cost-based Risk Priority Number (RPNmc). The main objective of this application is to identify the most critical failure modes affecting the pump performance and to rank them according to their level of risk in order to improve maintenance decision-making and reduce unexpected downtime.

The traditional RPN method is based on the evaluation of three main factors: Severity (S), Occurrence (O), and Detection (D). These factors are combined to calculate the Risk Priority Number, which helps determine the criticality level of each failure mode. However, this conventional method presents certain limitations because it assigns the same importance to all criteria. Therefore, the RPNw method was developed by introducing weighting coefficients for the different factors using Multi-Criteria Decision-Making (MCDM) techniques such as the AHP method, allowing more accurate and realistic results[28].

On the other hand, the RPNmc method incorporates the cost aspect into the risk assessment process by considering the economic impact of failures. This approach helps prioritize maintenance actions toward failures that generate higher financial losses or significantly affect the operational continuity of the system.

Through the application of these methods to the High Pressure Pump, different failure modes will be analyzed and compared in order to identify the most effective approach for prioritizing risks and supporting an appropriate maintenance strategy aimed at improving the reliability and operational performance of the pump.

III.2 failure Modes of the High-Pressure Pump

Table III-1Failure Modes of the High-Pressure Pump

N°	Failure Mode	Downtime hours (H:m)	Maintenance cost	Detection
1	Cavitation	1h	15000 .00	Noise and vibration analysis
2	Vibration	30min	13000.00	Vibration monitoring
3	MechanicalSeal Failure	1:30min	5500.00	Leakage inspection
4	Cavitation	30min	15000.00	Pressure fluctuation
5	Vibration	3:15min	13000.00	Vibration analysis
6	Suction/Discharge Blockage	45min /1h	22000.00	Pressure and flow monitoring
7	Air Binding	30min/2h	9000.00	Flow and vent inspection
8	Coupling Misalignment	30min	25000.00	Alignment inspection
9	Overheating	1h	6700.00	Temperature sensor
10	Vibration	2:15min	13000.00	Vibration monitoring
11	Damaged Bearings	2h	11500.00	Noise analysis
12	Insufficient Lubrication	45min	9700.00	Lubrication inspection
13	Mechanical Seal Failure	30min	10000.00	Leakage inspection
14	Vibration	45min	13000.00	Vibration analysis
15	Low Voltage	1:15min	4800.00	Voltage measurement
16	Reverse Rotation	30min	16000.00	Rotation direction inspection
17	Damaged Bearings	30min /45min	8000.00	Vibration monitoring
18	Vibration	30min	13000.00	Condition monitoring
19	Cavitation	30min	15000.00	Noise and pressure monitoring
20	Suction/Discharge Blockage	1:45min	3700.00	Flow monitoring
21	Pressure Gauge Breakage	30min	9800.00	Visual inspection
22	Mechanical Seal Failure	45min	5600.00	Leakage monitoring
23	Overheating	45min	7300.00	Thermal monitoring
24	Vibration	2h	13000.00	Vibration analysis
25	Cavitation	1h	15000.00	Pressure monitoring
26	Vibration	45min	8000.00	Vibration analysis

This table (Table III-1), extracted from the table included in the annexes, presents the main failure modes of the high-pressure pump, including downtime duration, maintenance cost, and the detection methods used for each failure, in order to improve maintenance operations and reduce the impact of failures on system performance.

III.3 Applying the FMECA method

- **Criticality Calculation:**

C= O×S×D……………. (III-1)

Table III-2Evaluation Criteria and Scoring Scale for Occurrence, Detection, and Severity Factors

	Frequency of Occurrence of Failure (O)	Detectability of the Failure (D)	Severity of Failure Effects (S)
1	The participant has no memory of it	Certain detection	The failure does not stop production for more than 10 min
2	It has already happened 1 or 2 times / 6 months	Detectable by the operator	Production stoppage between 10 and 30 min
3	It has already happened several times / month	Difficult to detect	Production stoppage between 30 and 45 min
4	It will certainly happen	Undetectable	The failure stops production for more than 45 min and/or causes serious problems for people or the installation

The table(III-2) presents the classification of failure severity based on their occurrence frequency, detectability, and impact on production, in order to assess the level of risk and determine priorities,after evaluating each FMECA criterion, we apply the method to the pump using the Table(III-2)

III.4 The application of FMECA method

The next table shows the application of the FMECA method on the water pump HP:

Table III-3The application of FMECA method on water pump HP

The application of FMECA method on water pump HP								
Steps in the process	Failure Mode	Failure Causes	Failure Effects	Occurrence (1-4)	Detection (1-4)	Severity (1-4)	Risk Priority Number (RPN)	Action to Reduce Occurrence of Failure
Suction Phase	Cavitation	Low suction pressure (NPSH)	Impeller damage + noise	**3**	**3**	**4**	**36**	Improve suction conditions
Rotation Phase	Vibration	Imbalance / misalignment	Bearing wear	**4**	**2**	**3**	**24**	Dynamic balancing
Sealing Process	Mechanical Seal Failure	Wear/leakage	Fluid loss	**3**	**2**	**4**	**24**	Replace seal periodically
Cooling Phase	Overheating	Poor cooling	Internal damage	**2**	**2**	**4**	**16**	Improve cooling system
Flow Process	Blockage	Pipe clogging	Flow reduction	**2**	**2**	**3**	**12**	Regular cleaning
Priming Phase	Air Binding	Air ingress	Efficiency loss	**2**	**4**	**2**	**16**	Ensure tight sealing
Transmission Phase	Misalignment	Installation error	Vibration	**2**	**2**	**3**	**12**	Alignment correction
Support Function	Bearing Damage	Lack of lubrication	Pump shutdown	**3**	**2**	**4**	**24**	Condition monitoring
Lubrication Phase	Insufficient Lubrication	Poor maintenance	Friction / wear	**3**	**2**	**3**	**18**	Preventive maintenance
Electrical	Low Voltage	Unstable supply	Poor performance	**2**	**2**	**3**	**12**	Use voltage stabilizer
Electrical	Reverse Rotation	Wrong wiring	Motor damage	**2**	**3**	**4**	**24**	Check connections
Instrumentati on	Pressure Gauge Failure	Overpressure	Incorrect reading	**2**	**3**	**2**	**12**	Install protection

The table (Table III- 3) shows an FMCEA analysis of pump failures, identifying failure modes, their causes and effects, evaluating risk (RPN), and suggesting actions to reduce failures

Ranking failures according to the RPN: (RPN = O *S *D).

- **Results and DiscussionFMECA(RPN)**

Through the analysis of this table, we observe that several failure modes have the same Risk Priority Number (RPN) and are therefore classified with the same value, despite differences in the evaluation of key indicators such as occurrence (O), severity (S), and detection (D).

For example, failure modes such as Vibration, Mechanical Seal Failure, Overheating, and Blockage all have the same RPN value of 24, even though their evaluations in the three indicators differ. Despite these differences, the same result is obtained when multiplying the values, which may lead to overlooking certain failure modes that could be more critical than others. This reflects a weakness in the effectiveness of the prioritization and decision-making process.

Table III-4Risk Priority Numbers (RPN) for each part of the water pump system

Steps in the process	Failure Mode	Occurrence (1-4)	Detection (1-4)	Severity (1-4)	RPN
Suction Phase	Cavitation	3	3	4	36
Rotation Phase	Vibration	4	2	3	24
Sealing Process	Mechanical Seal Failure	3	2	4	24
Support Function	Overheating	3	2	4	24
Electrical	Blockage	2	3	4	24
Lubrication Phase	Air Binding	3	2	3	18
Cooling Phase	Misalignment	2	2	4	16
Priming Phase	Bearing Damage	2	4	2	16
Flow Process	Insufficient Lubrication	2	2	3	12
Transmission Phase	Low Voltage	2	2	3	12
Electrical	Reverse Rotation	2	2	3	12
Instrumentation	Pressure Gauge Failure	2	3	2	12

Similarly, failure modes such as Misalignment and Bearing Damage share the same RPN value of 16, despite differences in their respective (O, S, D) ratings.

On the other hand, several failure modes including Insufficient Lubrication, Low Voltage, Reverse Rotation, and Pressure Gauge Failure all have the same RPN value of 12, even though their evaluations are not identical. This further highlights the limitation of the method in distinguishing between different levels of risk.

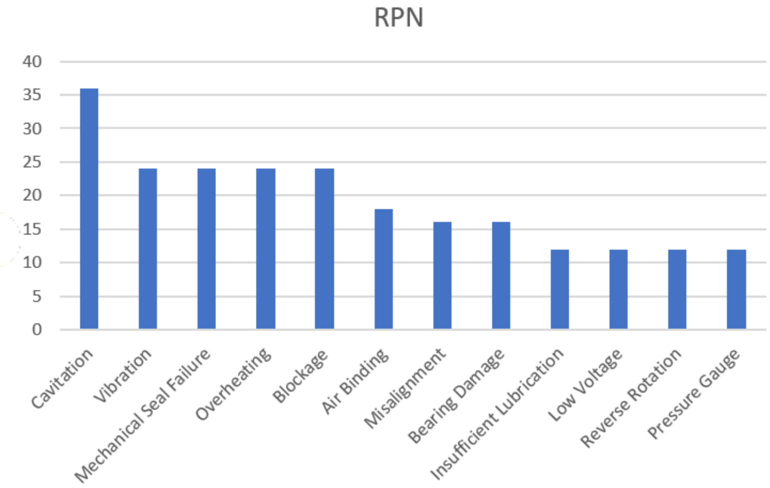

Figure III-1 :Risk Priority Numbers (RPN) for Each Failure Mode of the Water Pump System

These observations demonstrate that relying solely on the product of the three indicators in the traditional **FMECA (AMDEC)** approach may produce identical RPN values for different failure modes, which reduces the accuracy of risk prioritization and negatively affects maintenance decision-making.

III.5 Application of the 5 Whys Method to the Limitation of the RPN Calculation

After applying the Failure Modes, Effects and Criticality Analysis method, it was observed that several failure modes obtained identical RPN values despite differences in their severity, occurrence, and detectability levels. This situation makes it difficult to accurately prioritize failures and determine the most critical one requiring immediate maintenance action.

To better understand this limitation, the Five Whys method was applied in order to identify the root cause of this issue.

III.5.1 Problem:

Several failure modes obtained the same RPN value, leading to difficulties in maintenance prioritization.

- Why did several failure modes obtain the same RPN value?

Because different combinations of Severity (S), Occurrence (O), and Detection (D) can produce identical RPN results.

- ➢ Why do different parameter combinations produce identical RPN values?

  Because the RPN calculation is based only on multiplication:

$RPN = S \times O \times D$ ………………………..(III-2)

- ➢ Why is the multiplication method insufficient for accurate prioritization?

Because it does not reflect the relative importance of each evaluation criterion, especially the severity factor.

- ➢ Why is the severity factor not sufficiently emphasized in the traditional FMECA method?

Because the classical FMECA approach assigns equal importance to Severity, Occurrence, and Detection.

- ➢ Why does the traditional method assign equal weighting to all factors?

Because the classical FMECA method was originally designed as a simple qualitative risk assessment tool without advanced prioritization techniques

III.5.2 Root Cause

The root cause of this limitation is the traditional RPN calculation approach itself, which may generate identical priority values for different failure modes and therefore reduce the effectiveness of maintenance prioritization.

III.5.3 Improvement Recommendation

To overcome this limitation, it is recommended to integrate complementary decision-support techniques such as:

- Weighted evaluation criteria
- or Multi-Criteria Decision Making methods for more accurate failure prioritization.

III.6 FMECAw method

Failure Pattern and Effects Analysis and Weighted Criticality (FMECAw). In this case, weights were used to calculate the Weighted Risk Priority Number (RPNw). To achieve this, the AHP method was applied to determine the weights of the three criteria: probability of failure, severity of failure, and probability of failure detection. This resulted in objective weights that facilitate the effective use of the indicator data.

III.6.1 AHP method for calculating weights

III.6.1.1 The fondamental scale

Table III-5 The fundamental scale

Importance intensity	Definition	Explanation
1	Equal Importance	Both criteria have the same level of importance and contribute equally to the decision-making process.
3	Moderate importance of one over another	One criterion is slightly more important than the other based on practical experience and expert judgment.
5	Strong importance	One criterion is significantly more important and has a noticeable influence on achieving the objective.
7	Very strong importance	One criterion is clearly dominant and strongly preferred over the other.
9	Extreme importance	One criterion is considered absolutely more important, with overwhelming evidence supporting its preference
2,4,6,8	Intermediate value between the two adjacent	These values represent compromise judgments between two adjacent levels of importance

Table(III-5): Shows the importance scale (1–9) used to rate the relative importance between criteria

III.6.1.2 Pairwise Comparison

Table III-6Matrix table

	Severity (S)	Occurrence (O)	Detection (D)
Severity (S)	**1**	**0,33**	**0,33**
Occurrence (O)	**3**	**1**	**2**
Detection (D)	**3**	**0,5**	**1**

Table (III-6): Presents pairwise comparisons between criteria (Severity, Occurrence,Detection) to assess their relative influence

III.6.1.3 Weights

$$\text{Severity} = \left(1 \times \frac{1}{3} \times \frac{1}{3}\right)^{1/3} = 0.480749$$

$$\text{Occurrence} = (\, 3 \times 1 \times 2)^{1/3} = 1.817120$$

$$\text{Detection} = (\, 3 \times 0.5 \times 1)^{1/3} = 1.144714$$

Table III-7:weighting calculation

Severity	**0.480749**	**3.442583**	**0.139647**
Occurrence	**1.817120**	**3.442583**	**0.527836**
Detection	**1.144714**	**3.442583**	**0.332516**
Total	**3.442583**		**1**

Table (III-7): Displays the calculation of normalized weights for each criterion using the geometric mean method

weighted risk priority numbers (RPN_w) for each part of the pump system.

The weights were as follows: Ws = 0.139647, Wo = 0.527836,and W_D = 0.332516. The

III.6.1.4 The consistency test of the judgment matrix

- **Maximum eigenvalue calculation :**

$$\text{pairwise comparison} = \begin{bmatrix} 1 & 0.33 & 0.33 \\ 3 & 1 & 2 \\ 3 & 0.5 & 1 \end{bmatrix}$$

$$\text{Priority vector} = \begin{bmatrix} 0.139647 \\ 0.527836 \\ 0.332516 \end{bmatrix}$$

$$\text{pairwise comparison} \times \text{Priority vector} = \begin{bmatrix} 0.4235631 \\ 1.61189 \\ 1.015375 \end{bmatrix}$$

$$\text{Multiplication Result} \ \div \text{Priority vector} = \begin{bmatrix} 3.03309889 \\ 3.05377049 \\ 3.05316124 \end{bmatrix}$$

$$\text{Maximum Eigenvalue } (\lambda_{max}) = \frac{3.03309889+3.05377049+3.05361246}{3} = 3.04692728$$

Calculation of the consistency index (CI):

$$CI = \frac{\lambda max - n}{n-1} = \frac{3.04692728-3}{3-1} = 0.023463 \ldots\ldots\ldots\ldots\ldots \textbf{(III-3)}$$

Calculation of the consistency ratio (CR):

$$\text{consistency ratio (CR)} = \frac{Consistencyindex\ (CI)}{Rendomindex\ (RI)} \ldots\ldots\ldots\ldots\ldots \textbf{(III-4)}$$

Table III-8Random consensus index (RI)

N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

$$CR = \frac{0.023463}{0.58} = 0.040453$$

When CR < 0.1, the judgment matrix is considered to meet the consistency requirements. Otherwise, the judgment matrix should be modified.

After above calculation, CR = 0.040453 < 0.1 the consistency of each matrix is acceptable. It means that it is effective weight value of each evaluation factor W from the judgment matrix.

Table III-9:weighted risk priority numbers (RPNw) for each part of the pump system

Failure Mode	Occurrence (1-4)	Detection (1-4)	Severity (1-4)	(RPN)	(RPN_w)	RPN_w*100
Vibration	4	2	3	24	3.19531	319.531
Cavitation	3	3	4	36	3.13964	313.964
Mechanical SealFailure	3	2	4	24	2.80712	280.712
Overheating	3	2	4	24	2.80712	280.712
Air Binding	3	2	3	18	2.66748	266.748
Bearing Damage	2	4	2	16	2.66503	266.503
Blockage	2	3	4	24	2.61180	261.180
Low Voltage	3	2	2	12	2.52783	252.783
Pressure Gauge Failure	2	3	2	12	2.33251	233.251
Misalignment	2	2	4	16	2.27929	227.929
Insufficient Lubrication	2	2	3	12	2.13964	213.964
Reverse Rotation	2	2	3	12	2.13964	213.964

The table(Table III-9) presents the new RPN values after applying weighting factors.

Note: The weighted risk priority number (RPNw) is obtained by multiplying the values of the three indicators by their respective weights and then summing them, as shown in equation[28].

RPN_w= O·Wo + S·Ws + D·WD…………………………(III-5)

III.6.2 Results and Discussion FMECA$_W$

Through the analysis of the table, the impact of applying risk factor weights on the final ranking of failure mode priorities is clearly evident. This impact becomes particularly significant in cases where the Risk Priority Number (RPN) values are equal or very close, despite similarities in the evaluations of occurrence (O), severity (S), and detection (D).

For instance, several failure modes such as Mechanical Seal Failure, Overheating, and Blockage share the same RPN value (24). However, after applying the weighting method, differences appear in their weighted Risk Priority Numbers (RPNw), which leads to a more refined prioritization among them. Similarly, failure modes like Low Voltage, Pressure Gauge Failure, Insufficient Lubrication, and Reverse Rotation, all having an RPN of 12, are clearly differentiated once weights are introduced.

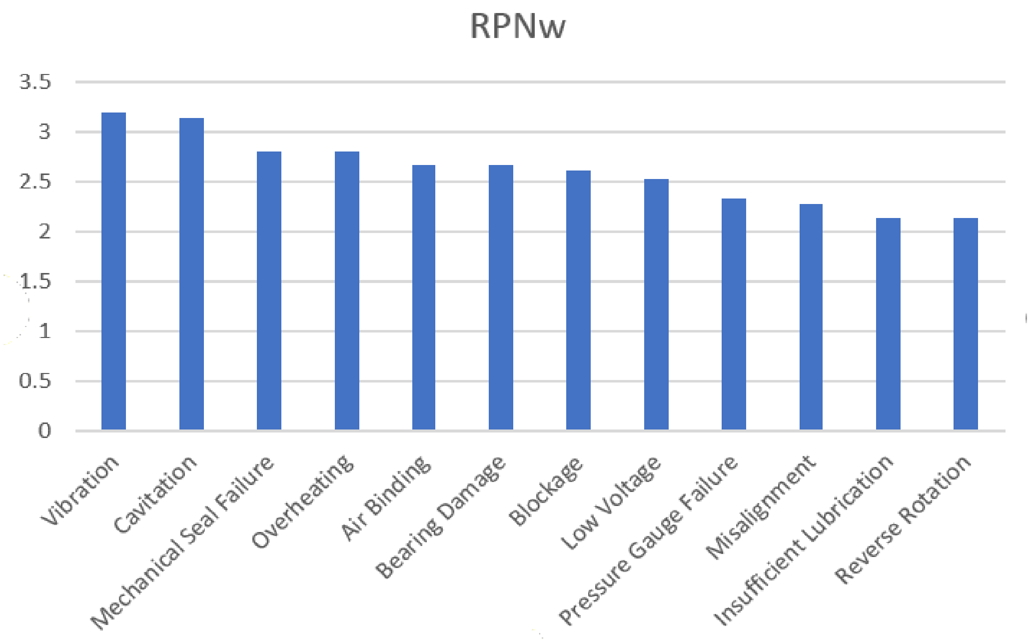

Figure III-2 :Weighted Risk Priority Numbers (RPNw) for Different Failure Modes of the Water Pump Syste

This demonstrates that relying solely on the traditional RPN may mask important differences between failure modes. The integration of weights allows for a more precise evaluation by accounting for the relative importance of each risk factor. As a result, the ranking becomes more representative of real operating conditions.

Therefore, incorporating risk factor weights is essential for improving the accuracy and reliability of risk analysis. It provides a more realistic prioritization of failures and supports better decision-making in maintenance planning and risk management.

III.7 FMECAmc method

III.7.1 Integration of Maintenance Cost

Integration of Maintenance Cost into the AHP-Based FMECA Model and Calculation of the Weighted Multicriteria Risk Priority Number (RPNmc)

Following the integration of a fourth criterion, namely maintenance cost (Ct), the criteria weights were recalculated using the Analytic Hierarchy Process methodology in order to ensure consistency and reliability in the evaluation process. The improved model considered four main criteria: occurrence of failure (O), severity of failure effects (S), detection capability (D), and maintenance cost (Ct).

The application of the AHP method resulted in the following weights:

$W_O = 0.29929$, $W_S = 0.19633$, $W_D = 0.06983$, and $W_{Ct} = 0.43455$. The obtained results indicate that the maintenance cost criterion has the highest relative importance among all considered criteria, highlighting the significant influence of the economic aspect on the overall risk assessment of the studied system.Based on these weights, the weighted multicriteria Risk Priority Number RPNmc was calculated according to the following expression[28]:

$RPNmc = O \times W_O + S \times W_S + D \times W_D + Ct \times W_{Ct}$……………………..**(III-6)**

Table III-10Cost ranking

Rank	Cost (Ct)
1	3700.00DA-9025.00DA
2	9025.00DA-14350.00DA
3	14350.00DA-19675.00DA
4	19675.00DA-25000.00DA

The table(III-10) shows the classification of costs into four ranks based on increasing cost ranges

Table III-11Multi-Criteria Weighted Risk Priority Numbers (RPNmc) for Each Component of the Water Pump System

Failure Mode	Occurrence (1-4)	Detection (1-4)	Severity (1-4)	Cost	RPN	RPN_W	RPN_{mC}	RPNmc*100
Blockage	2	3	4	4	24	2,611808	3.33159	333.159
Misalignment	2	2	4	4	16	2,279292	3.26176	326.176
Cavitation	3	3	4	3	36	3,139644	3.19633	319.633
Vibration	4	2	3	2	24	3,195317	2.79491	279.491
Mechanical Seal Failure	3	2	4	2	24	2,807128	2.69195	269.195
Reverse Rotation	2	2	3	3	12	2,139645	2.63088	263.088
Overheating	3	2	4	1	24	2,807128	2.2574	225.74
Insufficient Lubrication	2	2	3	2	12	2,139645	2.19633	219.633
BearingDamage	2	4	2	2	16	2,66503	2.13966	213.966
Pressure Gauge Failure	2	3	2	2	12	2,332514	2.06983	206.983
Air Binding	3	2	3	1	18	2,667481	2.06107	206.107
Low Voltage	3	2	2	1	12	2,527834	1.86474	186.474

The table(III-11) shows the updated RPN values after introducing a new criterion (cost).

III.7.2 Results and Discussion FMECAmc

Through the results presented in the table, it can be observed that the integration of the maintenance cost criterion (Ct) with the traditional FMECA factors - occurrence (O), detection (D), and severity (S) - significantly affected the final ranking of failure modes. The calculated RPNmc values provided a more discriminative and realistic classification compared to the conventional RPN approach.

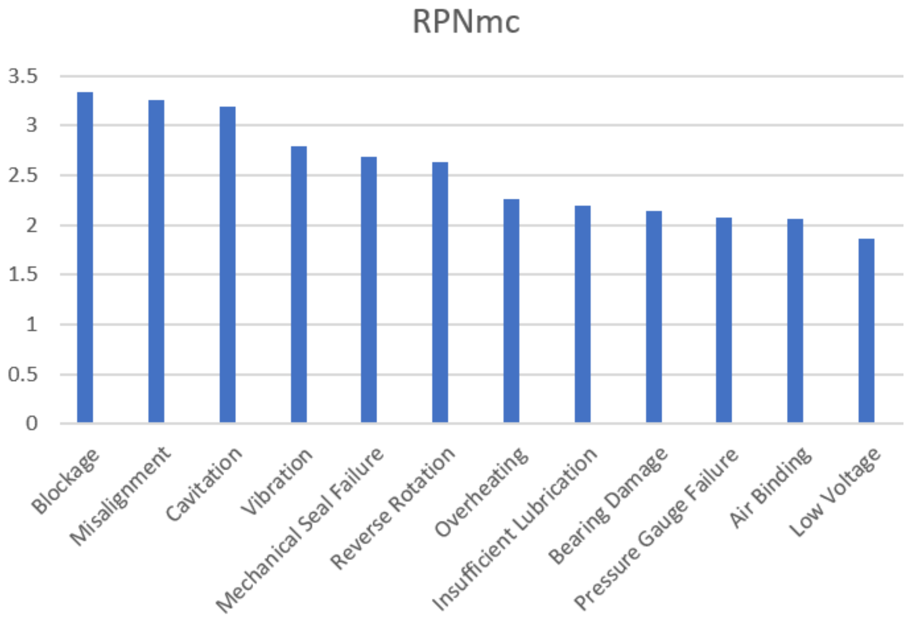

Figure III-3:Multi-Criteria Risk Priority Numbers (RPNmc) for Different Failure Modes of the Water Pump System

This effect is particularly evident for failure modes that obtained identical or close traditional RPN values. For example, Blockage**,** Vibration**,** Mechanical Seal Failure, and Overheating all recorded the same conventional RPN value of 24. However, after incorporating the maintenance cost criterion, theirRPNmc values became clearly differentiated. Blockage obtained the highest value (3.33159), followed by Vibration (2.79491), MechanicalSealFailure (2.69195), and Overheating (2.2574). This demonstrates that maintenance cost contributes significantly to distinguishing between failure modes that appear equally critical under the traditional RPN method.

In addition, the results reveal that some failure modes with higher conventional RPN values became more critical after applying the modified approach. For instance, Misalignment achieved an RPNmc value of 3.26176 and Cavitation reached 3.19633, both exceeding the value obtained for Vibration despite having different maintenance cost levels. This indicates that the inclusion of the maintenance cost criterion changes the prioritization order and provides a more realistic evaluation of failure criticality.

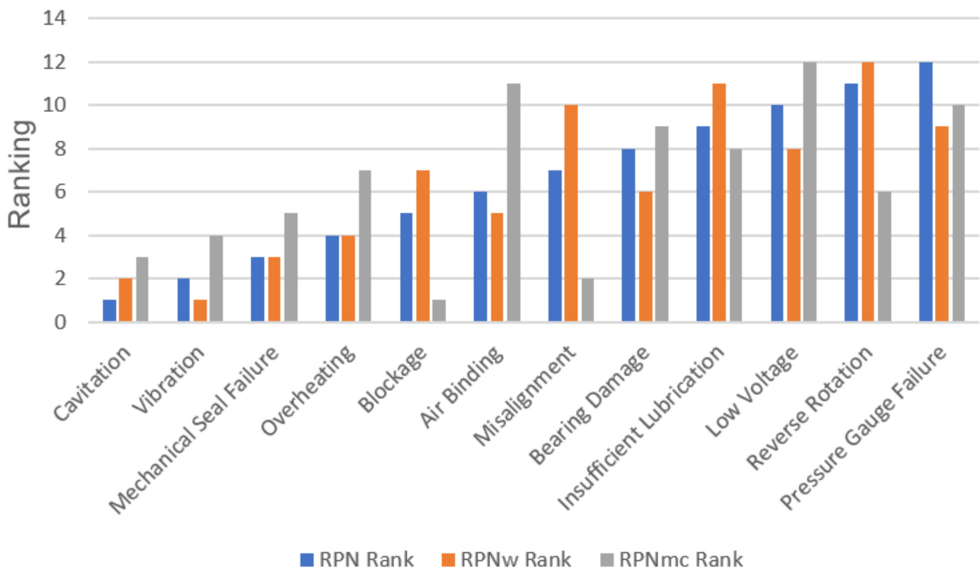

Figure III-4Comparison of failure classification rankings

A similar observation can be made for Reverse Rotation**,** Insufficient Lubrication, and Pressure Gauge Failure, which shared the same conventional RPN value of 12. After applying the modified method, their RPNmc values became different, leading to a clearer prioritization based on both technical and economic considerations.

Overall, incorporating the maintenance cost criterion into the FMECA analysis improves the accuracy and reliability of failure mode prioritization. The proposed RPNmc approach offers a more comprehensive assessment by considering not only occurrence, severity, and detectability, but also the economic impact associated with maintenance actions. Consequently, this method supports more balanced, practical, and effective maintenance decision-making for the high-pressure pump system.

III.8 Conclusion

In this chapter, the FMECA method and its improved approaches (RPNw and RPNct) were successfully applied to the high-pressure pump system in order to identify, evaluate, and rank critical failure modes. The obtained results highlighted the most critical components affecting the system reliability and maintenance performance. Furthermore, the comparison between the different methods demonstrated the effectiveness of integrating weighting factors and maintenance cost criteria in improving risk assessment accuracy and maintenance decision-making.

General Conclusion

General Conclusion

This study highlighted the importance of maintenance and failure analysis in improving the reliability of industrial systems through the case study of the High-Pressure Pump at the Ifri Gara water desalination station. The FMECA method was applied to identify critical failure modes and analyze their impact on the performance of the system, while different risk assessment approaches were used to prioritize failures.

The obtained results showed that the traditional RPN method is limited in accurately distinguishing between failure modes with similar values. Therefore, the weighted RPN (RPNw) method based on the AHP approach was introduced, in addition to integrating the maintenance cost criterion through the multi-criteria RPNmc method. This contributed to a more accurate and realistic classification of failures and improved maintenance decision-making.

The study also demonstrated that combining technical and economic criteria in failure analysis helps reduce unexpected downtime, improve maintenance planning, and enhance the reliability and operational performance of the pump system. Consequently, the use of multi-criteria analysis methods represents an effective approach for developing industrial maintenance strategies and improving system efficiency.

Bibliography

Bibliography

[1] A.Gaoud, «AQA-S5-ENS-NF-B-001-C,» S5- STATION D'IFRI GARA, OUARGLA, 2019.

[2] [Online]. Available: https://maps.app.goo.gl/ig5pEGkX71G4f4p5A.

[3] k. h. errahmane, "Etude de l'influence de la variation de la qualité d'eau d'alimentation sur le fonctionnement de l'osmoseur," UNIVERSITE KASDI MERBAH, OUARGLA, 2025.

[4] [En ligne]. Available: https://www.marlo-inc.com/news/1000-gpm-reverse-osmosis-ro-system.

[5] A. LENCASTRE, Hydraulique générale, Paris: Eyrolles, 1999, p. 28.

[6] K. I. .. K. Redouane, Etude, Conception et simulation d'une pompe centrifuge, OUARGLA: DSpace at Kasdi Merbah University Ouargla, 15/06/2019.

[7] [En ligne]. Available: https://pumpsdesign.com/volutes-diffusers/.

[8] S. I. e. G. Djamila, Calculs hydraulique et vérification de la pompe centrifuge 502-P-001A, Université 8 Mai 1945 – Guelma: theses-algerie, 2020.

[9] H. y. H. N. e. Islame., Etude des caractéristiques d'une pompe centrifuge., Université M'Hamed Bougara-Boumerdes, 2021.

[10] A. F. .. B. Abdelouafi, Etude des défaillances des pompes centrifuges, BEJAIA: UNIVERSITE Abderrahmane MIRA , 2020.

[11] S. M. .. FAYCAL, Etude et analyse du comportement dynamique d'une pompe centrifuge verticale multicellulaire., ANNABA: UNIVERSITÉ BADJI MOKHTAR, 2022.

[12] I. K. Bouabboune, «Analytical Analysis and Maintenance of a Centrifugal,» UNIVERSITY OF KASDI MERBAH , OUARGLA, 2021.

[13] G. M. L. YADDADEN Abdennour, Failure analysis at industrial machine (Turbine) by FTA (Fault tree analysis), OUARGLA: University of Kasdi Merbah, 2021.

[14] « Maintenance Généralités », esccal medjahed expertise etalonnage.

[15] J. HENGE, « Pratique de maintenance préventive », dunod.

[16] S. 6, «CB602 -Maintenance Management, Topic 1 -Introduction to Maintenance Management,» 2013.

[17] S. A. S. M. SAADAOUI Mounir, L'impact de la Maintenance sur la disponibilité des Equipements Pétroliers, OUARGLA: Université Kasdi Merbah , 2021.

[18] F. a. R. M. Trojan, Sorting maintenance types by multi-criteria analysis to clarify maintenance concepts in POM, 2016.

[19] B.Standard, Bs En 13306, 2010.

[20] «Normes Européennes EN 13306,» avril 2001.

[21] A. S. M. ,. V. B. D. S. P. S. O. G. J. Akshay Gaikwad, «ADVANCED FAILURE ANALYSIS TECHNIQUES FOR FIELD-FAILED UNITS IN INDUSTRIAL SYSTEMS,» E.C.E. Manipal University, India, 2020.

[22] M. Majka, «Mastering Root Cause Analysis with the 5 Whys Method,» LinkedIn, 2024.

[23] O. Serrat, «The Five Whys Technique,» Asian Development Bank, 2009.

[24] M. D. e. BEROUBA, «Analyse analytique FMD et AMDEC d'un compresseur,» université Kasdi Merbah, Ouargla, 2017.

[25] A. AHMED, «Analyse des défaillances des installations fixes de laSETRAM à Ouargla et choix d'une solution : étude de cas,» Université Kasdi M erbah Ouargla, 2025.

[26] V. B. e. T. J. Stewart, Multiple Criteria Decision Analysis, Boston, USA: Kluwer Academic Publishers, 2002.

[27] B. m. M. I. M. Ali, «Les influences de plusieurs méthodes d'aide à ladécision multicritères sur le choix du site d'unecentrale solaire,» Université Kasdi Merbah Ouargla, 2021 /2022.

[28] R. K. .. K. L. .. L. Guerrida, «A Multi-criteria Weighted Risk Priority Number Modelfor Evaluating Failure Modes and Effects: A Case Study,» p. 11, 9 MAI 2025.

ANNEXS

Historical failure record file (High Pressure Pump)						
N°	**Failure Mode**	**Failure Occurrence Date**	**Downtime hours (H:m)**	**Intervention end date & time**	**Time Between Failures (TBF)**	**Maintenance cost**
1	Cavitation	28/05/2013	1h	28/05/2013(13:15)	179.45	15000 .00
2	Vibration	04/06/2013	30min	04/06/2013(13:15)	30.85	13000.00
3	MechanicalSeal Failure	05/06/2013	1:30min	05/06/2013(21:30)	222.95	5500.00
4	Cavitation	15/06/2013	30min	15/06/2013(05:15)	177.15	15000.00
5	Vibration	22/06/2013	3:15min	22/06/2013(17:45)	94.55	13000.00
16	Suction/Discharge Blockage	26/06/2013	45min /1h	26/06/2013(16:45/ 23 :00)	12	22000.00
7	Air Binding	27/06/2013	30min /2h	27/06/2013(06:15/ 13 :15)	15.30	9000.00
8	Coupling Misalignment	28/06/2013	30min	28/06/2013(00:45)	71.55	25000.00
9	Overheating	01/07/2013	1h	01/07/2013(01:00)	74.45	6700.00
10	Vibration	04/07/2013	2:15min	04/07/2013(06:00)	8026	13000.00
11	Damaged Bearings	07/06/2014	2h	07/06/2014(18:00)	238	11500.00
12	Insufficient Lubrication	17/06/2014	45min	17/06/2014(16:45 /21 :30)	28.7	9700.00
13	Mechanical Seal Failure	18/06/2014	30min	18/06/2014(22:30)	262.65	10000.00
14	Vibration	29/07/2014	45min	29/07/2014(22:00)	30.45	13000.00
15	Low Voltage	01/07/2014	1:15min	01/07/2014(06:00)	40	4800.00
16	Reverse Rotation	02/07/2014	30min	02/07/2014(22:30)	19.9	16000.00
17	Damaged Bearings	03/07/2014	30min /45min	03/07/2014(3:00 / 08 :30)	9.8	8000.00

18	Vibration	04/07/2014	30min	04/07/2014 (03:00/08 :45)	73.3	13000.00
19	Cavitation	07/07/2014	30min	07/07/2014(10:45)	50.7	15000.00
20	Suction/Discharge Blockage	17/07/2014	1:45min	17/07/2014 (15:00/21:00)	185.75	3700.00
21	Pressure Gauge Breakage	07/03/2015	30min	07/03/2015(10:00)	1243.15	9800.00
22	Mechanical Seal Failure	16/03/2015	45min	16/03/2015(06:00)	2577.45	5600.00
23	Overheating	09/04/2015	45min	09/04/2015(12:30)	571.7	7300.00
24	Vibration	30/05/2016	2h	30/05/2016(10:00)	1233.3	13000.00
25	Cavitation	20/06/2016	1h	20/06/2016(20:15)	459.45	15000.00
26	Vibration	04/07/2016	45min	04/07/2016(00:45)	301.6	8000.00

Abstract

This study aims to apply and improve the Failure Modes, Effects, and Criticality Analysis (FMECA) method on a high-pressure pump used in the Ifri Gara water treatment station in order to evaluate and prioritize failure modes according to their criticality. First, the traditional Risk Priority Number (RPN) method based on occurrence, severity, and detection criteria was applied. The results revealed limitations in the conventional approach, particularly the occurrence of identical RPN values for different failure modes despite differences in their actual impact.

To overcome these limitations, the Analytic Hierarchy Process (AHP) was integrated to determine the relative weights of the criteria and develop the FMECAw model. In addition, maintenance cost was introduced as an extra criterion within a multicriteria model (FMECAmc). The obtained results showed that integrating weights and maintenance cost improved the accuracy of failure classification and supported more effective and realistic maintenance decision-making, contributing to enhanced reliability and operational performance of the pumping system.

Keywords:AHP,Failure Analysis,FMECA,High-Pressure Pump, Maintenance CostMaintenance.

استخدام منهجية FMECA المدعمة باتخاذ القرار متعدد المعايير في اختيار إجراءات الصيانة

ملخـص:

تهدف هذه الدراسة إلى تطبيق وتحسين منهجية تحليل أنماط وتأثيرات وحرجية الأعطال (FMECA) على مضخة الضغط العالي بمحطة إفري قارة لمعالجة المياه، من أجل تقييم الأعطال وترتيبها حسب درجة الخطورة. تم في البداية تطبيق الطريقة التقليدية المعتمدة على رقم أولوية المخاطر (RPN) باستخدام معايير الحدوث والشدة والكشف، حيث أظهرت النتائج وجود قيم متساوية لبعض الأعطال رغم اختلاف تأثيرها الحقيقي.

ولتجاوز هذه المحدودية، تم دمج طريقة التحليل الهرمي (AHP) لتحديد أوزان المعايير وتطوير نموذج (FMECAw)، ثم إضافة معيار تكلفة الصيانة ضمن نموذج متعدد المعايير .(FMECAmc) وقد أظهرت النتائج أن إدماج الأوزان وتكلفة الصيانة ساهم في تحسين دقة تصنيف الأعطال ودعم اتخاذ قرارات صيانة أكثر فعالية وواقعية، مما يساعد على تحسين موثوقية وأداء نظام الضخ.

الكلمات المفتاحية:

FMECA،AHP، رقم أولوية المخاطر، تكلفة الصيانة، مضخة الضغط العالي، تحليل الأعطال، الصيانة.