Chapter 1 : Industrial Maintenance

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Objectifs

- Ensure the continuity of service of an industrial facility ;
- identifying the functions and components of electrical and electronic equipment ;
- determining the causes of system failures and repairing them.

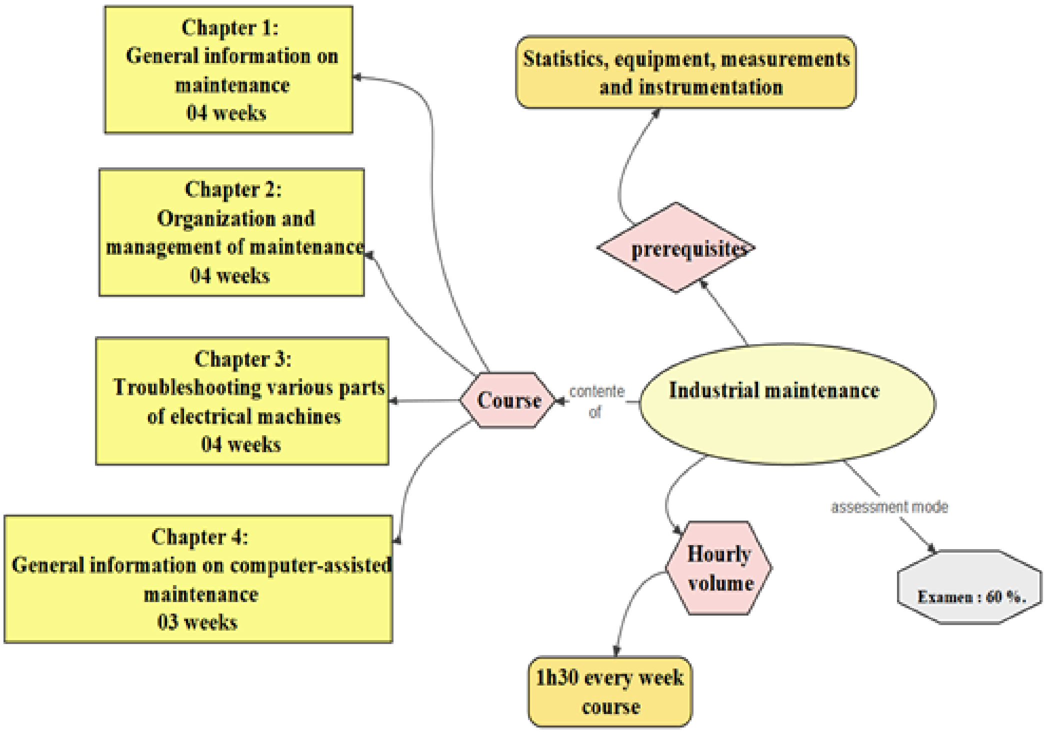
Introduction

The growing role of maintenance in various industrial sectors, both small and large, requires technicians to work on increasingly varied equipment and to deepen their knowledge of all technologies. Additionally, with the growth of industrial companies and the increasing complexity and interconnection of technologies, it has become necessary not only to maintain and repair equipment but also to effectively organize and manage the maintenance department. Therefore, the maintenance department plays a crucial and effective role in maintaining equipment, thereby increasing its uptime and reliability. This course is a real guide for those responsible for the maintenance department. At the beginning of this course, we will see general information on maintenance. Followed by a detailed presentation on the organization and management of maintenance. After, we present the troubleshooting of the different parts of electrical machines. At the end of the course, you will have presented general information on computer-aided maintenance. For more details, refer to the figure below, which outlines the overall content of this course according to the framework.

This handout is primarily intended for third-year undergraduate students in electrical engineering. In this regard, industrial companies and other maintenance engineers will also find this manual very useful in their daily work.

Various technical guides, catalogues, books, theses, and other sources inspired the texts presented in this handout.

Any comments, suggestions, or constructive criticism that could improve the texts thus developed will be greatly appreciated.



presentation of the industrial maintenance course

I General information on maintenance

1. Introduction

Maintenance has become essential for the proper functioning and competitiveness of a business. All sectors of activity are concerned by the reliability and condition of their production tools. Monitoring facilities to prevent breakdowns, optimize operations, and plan maintenance are essential for business economics.

2. The history and evolution of industrial maintenance

2.1. Origins of maintenance (before 1940)

In its early days, maintenance was based solely on corrective (or reparative) maintenance. Its primary objective was to repair after the breakdown, with no proactive strategy, standardization, or quality approach. Its terminology was limited to "repair" and "maintenance.".

2.2. Industrialization and Preventive Maintenance (1940–1960)

Following World War II and the massive mechanization, a new form of maintenance emerged: preventive maintenance, maintenance characterized by planned interventions (schedule or number of operating hours). Its main objective is to reduce unplanned shutdowns. During this period, the first planned maintenance programs appear.

2.3. Start of standardization

During this period, the emergence of standardized and structuring concepts, such as ISO, began to formalize industrial terms, and the introduction of the concept of reliability, availability and safety. Also, the introduction of new terminologies such as MTBF (mean time between failures), and MTTR (mean time to repair). And the emergence of key concepts such as systematic preventive maintenance (schedule), and conditional maintenance (according to the measured condition).

2.4. Emergence of modern maintenance (1980–2000)

Ø Implementation of advanced methodologies:

o TPM (Total Productive Maintenance) – Japan, automotive industry.

o RCM (Reliability-Centered Maintenance) – aeronautics sector.

Ø Enhanced terminology:

o Predictive maintenance: based on real-world data (sensors, vibrations, thermography, etc.).

o CMMS (Computerized Maintenance Management System): digitization of processes.

Ø Importants standards :

o NF X60-010 (France): maintenance terminology.

o Introduction of ISO 9000 standards with an "equipment control" component.

2.5. Smart and standardized maintenance (2000–present)

Ø Maintenance integrated into asset management:

o ISO 55000 Standard (Asset Management)

Ø Predictive maintenance + artificial intelligence = prescriptive maintenance :

o AI and IoT make it possible to anticipate breakdowns.

Ø Recent concepts:

o Industry 4.0

o Maintenance 4.0

o Digital twins

Ø Standardized terminologies:

o ISO 14224: reliability and data collection.

o EN 13306: standardized maintenance terminology.

3. Concepts and Definitions

3.1. Definition of industrial maintenance

According to AFNOR, through the NF X 60-010 standard: all actions enabling an asset to be maintained or restored to a specified state or capable of providing a specific service. Proper maintenance means ensuring all of these operations at the optimal cost.

The definition of maintenance therefore reveals four notions:

- Maintain, which involves monitoring and surveillance
- Restore, which implies the idea of correcting a defect
- Specified condition and determined service, which specifies the level of skills
- Optimal cost, which determines all operations with a view to economic efficiency

  Preserving: this means troubleshooting and repairing equipment to ensure continuity of production: Maintaining means putting up with the equipment.

  Maintaining: This involves choosing ways to prevent, correct, or renovate equipment based on usage and its economic criticality, in order to optimize overall costs.

  Maintaining means controlling.

3.2. Definition of Maintainability

According to the **CEN 13306 standard**, it is defined as: “Under given conditions of use, maintainability is the ability of an item to be maintained or restored to a state where it can perform a required function, when

3.3. Definition of Reliability

The ability of a system to perform a required function under given conditions during a given time interval.

3.4. Definition Availability

The ability of a system to be able to perform a required function under given conditions at a given time, assuming that the supply of external means is assured

3.5. Concept of failure

a) Definition of failure (according to standard NF 60-011):

"Impairment or cessation of an asset to perform its required function" , malfunction, damage, anomalies, breakdowns, incidents, defects, breakdowns, deterioration).

A failure can be:

- **Partial**: There is an impairment in the asset's ability to perform its required function.
- **Complete**: There is a cessation of the asset's ability to perform its required function.
- **Intermittent**: The asset regains its ability after a limited period of corrective action.

b) Evolution of the deterioration of the property

Degradation is the loss of performance of a function without functional consequences on the overall system, as shown in Figure 1.

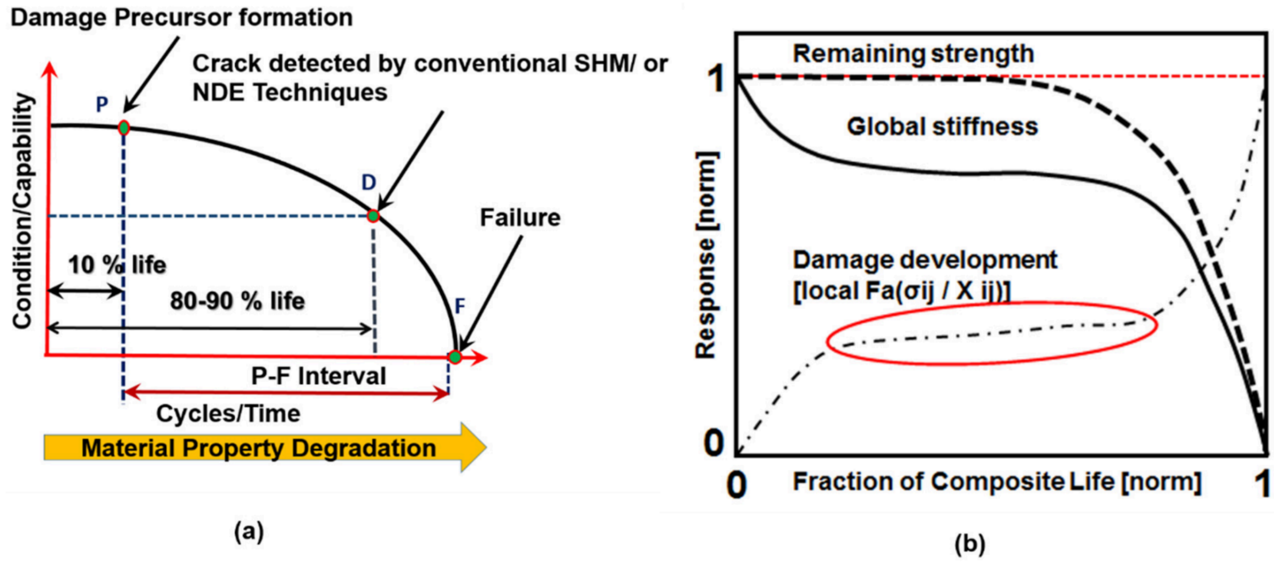


Figure 1 : Evolution of the deterioration of the property

4. Role of equipment maintenance and troubleshooting in industry

The role of equipment maintenance and troubleshooting in industry is fundamental to ensuring the performance, safety, and competitiveness of industrial companies.

4.1. Main objectives of industrial maintenance:

- Ensure equipment availability
- Prevent breakdowns and avoid unplanned downtime
- Improve equipment lifespan
- Reduce production costs related to failures
- Guarantee personal safety and regulatory compliance
- Improve the quality of finished products

4.2. Role of troubleshooting in industry

Troubleshooting is an immediate and corrective action, carried out following a breakdown or malfunction.

4.3. Troubleshooting objectives:

- Quickly restore faulty equipment to service
- Limit production losses
- Avoid cascading effects (entire line failure, delays, waste)
- Analyze the cause of the failure to prevent its recurrence

5. Elements of mathematics applied to maintenance

Here is a clear and structured summary of the elements of mathematics applied to industrial maintenance, very useful for planning, breakdown analysis, reliability, and optimization of interventions.

5.1. Statistics and probability

Applied to failure and downtime analysis, equipment reliability assessment, and failure prediction (predictive maintenance). Key concepts are mean, median, and standard deviation, probability of failure in a time interval, and exponential distribution, Weibull distribution (lifetime modeling).

5.2. Reliability and Maintainability (RAMS)

RAMS = Reliability, Availability, Maintainability, Safety

There are several indicators for the calculation of maintenance such as, MTBF (Mean Time Between Failures), MTTR (Mean Time to Repair), and availability (D) which is calculated as follows:
.

D=MTBF/(MTBF+MTTR)

And the failure rate (λ) which is calculated as follows:

λ = 1/MTBF

Also, for the calculation of maintenance several mathematical tools are needed, such as reliability diagrams, fault trees (FTA) and FMEA analysis.

5.3. Optimization

The objectives of optimization in maintenance are to plan maintenance to minimize costs, maximize availability and choose the best maintenance interval. Using the following mathematical tools:

- Linear programming: optimizing resources (e.g., technician scheduling);
- Decision-making methods: decision tree, total cost of ownership (TCO);
- Simulation methods: Monte Carlo, queues (to model interventions).

5.4. Maintenance Interval Calculations

Maintenance interval calculations are based on statistical laws (exponential, Weibull). Their objective is to find the optimal intervention point before a breakdown. In order to integrate it into CMMS software.

6. Equipment behavior in service

In-service equipment behavior refers to how an industrial equipment or system evolves over its operational life cycle in response to its use, stresses, and environmental conditions. Understanding this behavior is essential for implementing effective maintenance, ensuring reliability, and optimizing interventions

6.1. Typical phases of in-service behavior

Represented by the Bathtub curve, they describe the evolution of the failure rate over time, as shown in figure 2:

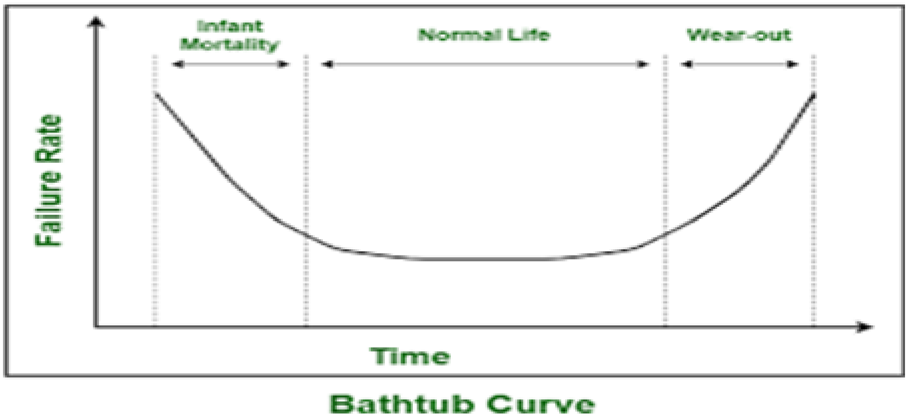


Figure 2 :The Bathtub curve

6.2. Why monitor in-service behavior?

Typically, in-service behavior is monitored for:

- Anticipate breakdowns → preventive or predictive maintenance
- Extend useful life
- Avoid unplanned downtime
- Reduce replacement or emergency response costs

7. Failure rate and reliability laws

Two fundamental concepts in industrial maintenance for modeling the lifespan of equipment and anticipating breakdowns, which are the failure rate and reliability laws.

7.1. Failure rate (λ or h(t))

The failure rate, also known as the risk function, measures the instantaneous probability of failure of a piece of equipment at a given time, assuming it is still functioning at that time.

$$h(t) = \frac{f(t)}{R(t)}$$

f(t): probability density of failure

R(t): reliability, i.e. the probability that the system will function until time t

7.2. Reliability laws (statistical models of behavior over time)

These laws make it possible to model the operating time before failure of equipment.

a) Exponential law

Used to model a constant failure rate (random failures). This is an ideal law for the stable useful life phase (bathtub curve).

$$R(t) = \exp(-\lambda \times t)$$

λ: constant failure rate

MTBF = 1/λ

b) Weibull law

This is widely used in maintenance because it models three types of behavior:

- Youth (early breakdowns)
- Random
- Wear (increasing breakdowns)

This law is represented by the following function:

$$R(t) = \exp(\frac{-t}{\eta} \times \beta)$$

η: scale parameter (characteristic time)

β: shape parameter:

- β<1: early failures (decreasing)
- β=1: random failures (exponential law)
- β>1: wear (increasing rate)

Example: motors, bearings, pumps.

c) Normal (or Gaussian) law

Est une distribution de probabilité continue caractérisée par une courbe en cloche symétrique, voir la figure 3. Elle est définie par deux paramètres : la moyenne (μ) et l'écart type (σ). This law is used to model lifetimes with low variability. Not very suitable for sudden mechanical failures, but useful for well-controlled processes.

In a normal distribution:

1. The mean (μ) is the center of the distribution.
2. The standard deviation (σ) determines the spread of the distribution.
3. The distribution is symmetric around the mean.
4. The total area under the curve is 1.

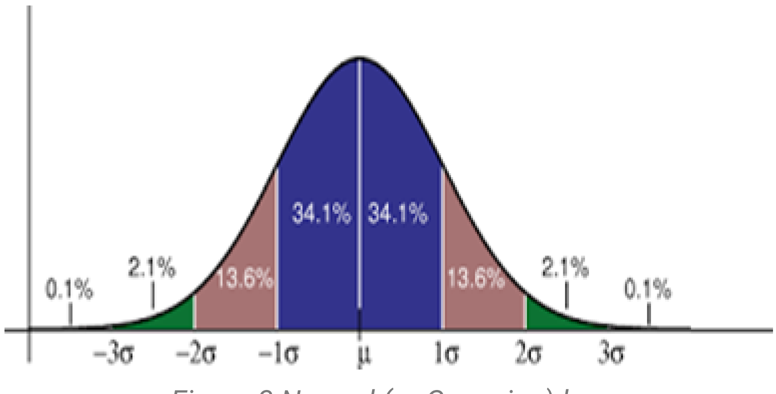


Figure 3 Normal (or Gaussian) law

8. Reliability of a system

Determining the reliability of an electronic, mechanical, or other system first requires knowing the reliability law (or failure law) of each component involved in the system.

This is straightforward for certain types of systems, such as electronic systems, but it is not the case for mechanical systems due to the complexity of the system's structure. Mechanical systems comprise sets of technological elements interconnected by complex static and dynamic relationships.

For an electronic system, each component has a significant impact on the overall system reliability. Therefore, the reliability of the system is calculated based on the reliability of all its elements. The calculations are carried out under the assumption that failure rates are constant over time, a reasonable assumption for most components, which simplifies the calculations significantly.

The reliability of a mechanical system, unlike electronics, is based on the reliability of a few elementary components responsible for its malfunction, called “responsible” or “critical” components (sometimes just one).

8.1. Reliability of a system consisting of several components

a) In series:

The reliability R_S of a set of n components connected in series is equal to the product of the respective reliabilities R_A, R_B, R_C, R_n of each component.

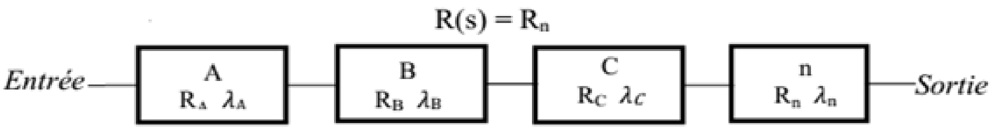


Figure 4 : Reliability of a system in series

$$Rs = R_A \times R_B \times R_C .... \times R_n$$

$$Rs = (\exp(-\lambda_A \times t)).(\exp(-\lambda_B \times t)).(\exp(-\lambda_C \times t)).....(\exp(-\lambda_n \times t))$$

with :

$$MTBF_S = \frac{1}{\lambda_A+\lambda_B+\lambda_C.....+\lambda_n}$$

If, in addition, the components are identical:

$$\lambda_A = \lambda_B = \lambda_C = ... = \lambda_n$$

So :

$$Rs = \exp(-n \times \lambda \times t)$$

And:

$$MTBF_s = \frac{1}{n \times \lambda}$$

Example 1: Consider a radio set consisting of four components connected in series: a power supply R_A = 0.95, a receiver R_B = 0.92; an amplifier R_C = 0.97, and a speaker R_D = 0.89;

Determine the reliability R_S of the device.

R_S= R_A. R_B .R_C. R_D=0.95x 0.92x0.97x0.89=0.7545 (i.e. a reliability of approximately 75%).

Example 2: A production machine with a total operating life of 1,500 hours consists of four subsystems A, B, C, and D connected in series and having the following respective MTBFs:

$MTBF_A$ = 4500 hours, $MTBF_B$ = 3200 hours, $MTBF_C$ = 6000 hours, $MTBF_D$ = 10500 hours.

1- Determine the failure rates

2- Determine the overall MTBF

3- What is the probability that the system will last up to 5000 hours without failures?

Solution 2:

1- **The failure rates**

$\lambda_A = \frac{1}{MTBF_A} = \frac{1}{4500} = 0.0002222$ failure per hour

$\lambda_B = \frac{1}{MTBF_B} = \frac{1}{3200} = 0.000313$ failure per hour

$\lambda_C = \frac{1}{MTBF_C} = \frac{1}{6000} = 0.000167$ failure per hour

$\lambda_D = \frac{1}{MTBF_D} = \frac{1}{10500} = 0.000095$ failure per hour

Then: $\lambda_S = \lambda_A + \lambda_B + \lambda_C + \lambda_D = 0.000222 + 0.000313 + 0.000167 + 0.000095 = 0.000797$ failure per hour

The reliability of the system is: $R_S = \exp(-\lambda_S \times t) = \exp(-0.000797 \times 1500) = 0.303(30.3\%)$

2- **The overall MTBF**

$MTBF_S = \frac{1}{\lambda_S} = \frac{1}{0.000797} = 1255$ Hours

A time of 1255 hours between two failures.

3- The probability that the system will last up to 5000 hours without failures

b) In parallel:

The reliability of a system can be increased by placing components in parallel. A device consisting of n elements in parallel can only fail if all n components fail simultaneously.

If F_i is the probability of failure of a component, the associated reliability R_i is its complement: $F_i = 1 - R_i$

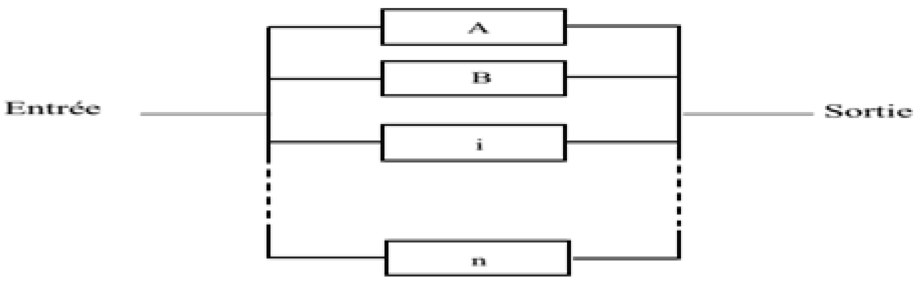


Figure 5 : Reliability of a system in parallel

Let the “n” components in the figure below be connected in parallel. If the probability of failure for each element identified (i) is noted Fi, then:

$Rs = 1 - (1 - R)^n$

Three devices A, B and C with the same reliability R_A=R_B=R_C= 0.75, are connected in parallel.

1- Determine the reliability of the set

$Rs = 1 - (1 - R)^n = 1 - (1 - 0.75)^3 = 0.984$

If we reduce the number of components to two

$Rs = 1 - (1 - R)^n = 1 - (1 - 0.75)^2 = 0.9375$

If we put four devices in parallel

$Rs = 1 - (1 - R)^n = 1 - (1 - 0.75)^4 = 0.9961$

2- How many devices in parallel would need to be used to have an overall reliability of 0.999 (99.9%)?

$Rs = 1 - (1 - R)^n$

$1 - (1 - 0.75)^n = 0.999n = 4.983$

Which implies having at least five devices in parallel

3. If we want to have an overall reliability of 99%, with only three devices in parallel, what should be the reliability R of each of these devices?

$Rs = 1 - (1 - R)^3 = 0.99$

R = 0.7846 A minimum reliability of 78.46%

c) Series / Parallel combination:

It is the combination of the two previous subparagraphs.

The reliability of the three identical components A, B and C is 0.65, that of D is 0.96; that of E is 0.92, that of G is 0.87, that of F is 0.89 and that of H is 1 (100%). The overall reliability R is expressed here by:

$$R_S = [1-(1-0.65)^3].[0.96].[1-(1-0{,}92.0{,}87)(1-0{,}89.1] = 0{,}957.0{,}96.0{,}978 = 0{,}8986\ (environ\ 90\%)$$

9. The different forms of maintenance

The choice between maintenance methods is made within the framework of the maintenance policy and must be made in agreement with the company's management. To choose, it is, therefore, necessary to be informed of management's objectives and maintenance policy guidelines, as well as to understand the operation and characteristics of the equipment, its behavior in operation, the conditions for applying each method, maintenance costs, and the costs of lost production.

9.1. Corrective maintenance

AFNOR definition (standard X 60-010): "Maintenance operation performed after a failure."

Corrective maintenance is a defensive (enduring) approach while awaiting a random failure, an approach characteristic of traditional maintenance.

After a failure occurs, several operations are implemented, the definitions of which are provided below. These operations are carried out in stages (in order):

- **Testing:** i.e., comparing measurements with a reference.
- **Detection** or action to detect the occurrence of a fault.
- **Location** or action leading to a precise search for the elements through which the fault is manifested.
- **Diagnosis**,Identification, and analysis of the causes of the fault.
- **Troubleshooting**, repair, or restoration (with or without modification).
- **Checking** for proper operation after the intervention.
- **Possible improvement**: i.e., preventing the fault from recurring.
- **Logging** or storing the intervention for future use.

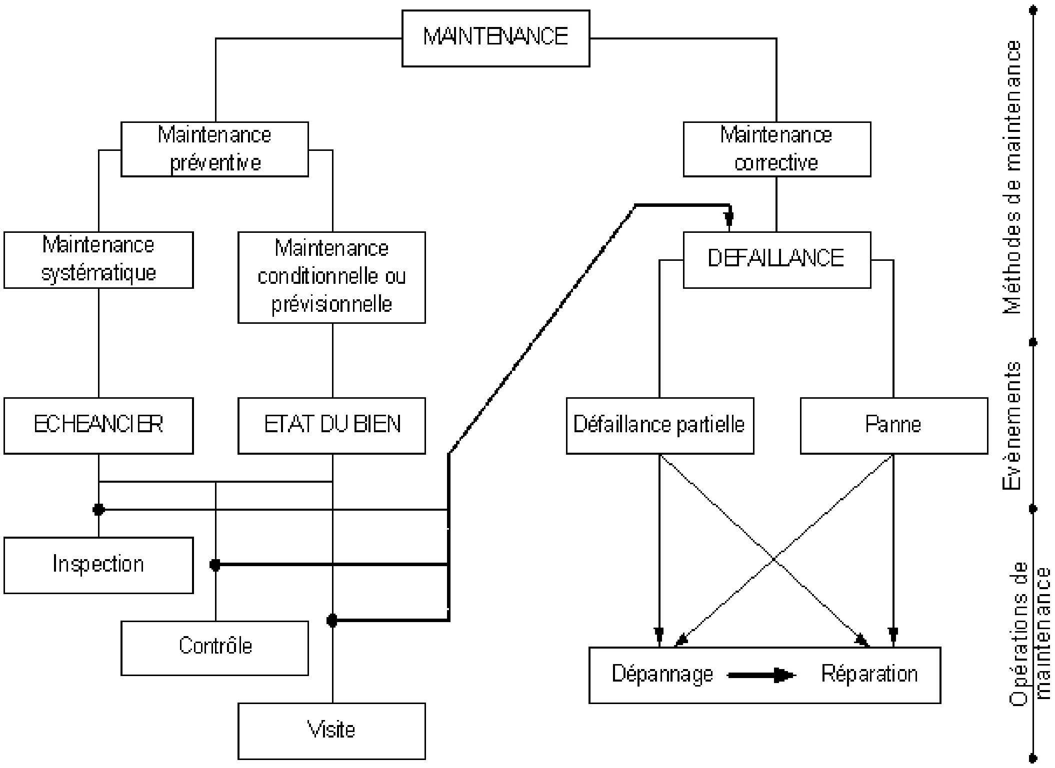


Figure 6 : The different forms of maintenance

9.2. Preventive or planned maintenance

Maintenance is performed according to predetermined criteria to reduce the likelihood of asset failure or degradation of the service provided.

It must prevent equipment failures during use.

A cost analysis must demonstrate a gain in terms of the failures it prevents.

a) Objectives of preventive maintenance:

- Increase equipment lifespan.
- Reduce the likelihood of in-service failures.
- Reduce downtime in the event of overhauls or breakdowns.
- Prevent and plan costly corrective maintenance interventions.
- Enable corrective maintenance decisions to be made under optimal conditions.
- Avoid abnormal consumption of energy, lubricants, etc.
- Improve working conditions for production personnel.
- Reduce maintenance budgets.
- Eliminate the causes of serious accidents.

9.3. Preventive maintenance operations:

These operations are defined in the NF X 60-010 and NF EN 13306 standards.

- **Inspection:** Conformity checks are carried out by measuring, observing, testing, or calibrating significant characteristics. This allows anomalies to be identified and simple adjustments to be made that do not require specific tools or production or equipment shutdowns (no disassembly).

- **Control:** verification of compliance with pre-established data, followed by a judgment. This control can lead to corrective maintenance actions or result in a decision of refusal, acceptance, or postponement.

- **Visit:** a detailed and predetermined examination of all (general visit) or part (limited visit) of the property's different elements, which may involve first- and second-level maintenance operations; it may also lead to corrective maintenance.

- **Test:** comparison of the responses of a system concerning a reference system or a physical phenomenon significant for correct operation.

- **Standard exchange**: replacement of a defective part or sub-assembly with an identical part, new or previously reconditioned, in accordance with the manufacturer's instructions.

- **Overhaul:** A comprehensive set of examinations and actions carried out to maintain the availability and safety of an asset. An overhaul is often conducted at prescribed intervals or after a specified number of operations have been completed. An overhaul requires total or partial disassembly of the asset.

9.4. Systematic maintenance

Preventive maintenance is performed according to a schedule established by time or the number of units of use (other units may also be considered, such as quantity, length, mass of manufactured products, distance traveled, number of cycles performed, etc.).

This intervention frequency is determined from the time of commissioning or after a complete or partial overhaul.

9.5. Conditional maintenance

Predictive maintenance (non-standardized term). This is preventive maintenance, subject to a predetermined type of event (such as self-diagnosis, sensor information, or wear measurement).

Conditional maintenance, therefore, is experience-based maintenance that utilizes real-time information. It is characterized by the identification of weak points (monitoring these points and deciding on intervention if certain thresholds are reached).

Systematic inspections using non-destructive testing methods.

All equipment is affected; this conditional preventive maintenance is performed by taking relevant measurements on operating equipment.

The parameters measured may include:

- Oil level and quality.
- Temperatures and pressures.
- Voltage and current draw of electrical equipment.
- Vibrations and mechanical play.
- The equipment required to perform condition-based preventive maintenance must be reliable to ensure its continued usefulness. It is often expensive, but in well-chosen cases, it pays for itself quickly.

9.6. Improved maintenance

It is a "set of technical, administrative, and management measures intended to improve the operational safety of an asset without changing its required function" (NF EN 13306 standard).

Modifications were made to the original design to increase the lifespan of components, standardize them, reduce energy consumption, and improve maintainability.

a) Objectives of Improvative Maintenance

- Increased production performance.
- Increased reliability.
- Improved maintainability.
- Increased user safety.

10. Organization of maintenance and repair of electrical equipment

The organization aims to ensure the availability, safety and regulatory compliance of electrical installations.

10.1. Objectives of the organization

- Prevent breakdowns through regular checks.
- React quickly in the event of an electrical fault
- Ensure the safety of people and property
- Guarantee compliance with standards (NF C15-100, NFC 18-510, etc.)
- Optimize human and material resources.

10.2. Organization of electrical maintenance (preventive)

a) Planning

§ Development of an annual maintenance plan

§ Definition of intervention frequencies according to the type of equipment (panel, motors, transformers, cabinets, etc.)

§ Prioritization according to the criticality of the equipment

b) Typical interventions

Typical interventions are scheduled according to the following table:

Table 2 : Typical interventions

10.3. Organization of electrical troubleshooting (corrective)

a) Procedures in case of breakdown

1. Reporting the fault
2. Security (electrical lockout)
3. Rapid diagnosis (cause analysis)
4. Repair or replacement
5. Restart with testing
6. Intervention report + CMMS update

i) Resources needed

§ Team of trained electrical technicians (B0, H1, etc. accreditations)

§ Spare equipment available (critical spare parts)

§ Specialized tool kit

1 Priority criteria

§ Safety

§ Impact on Production

§ Estimated Downtime

§ Parts Availability

10.4. Monitoring and continuous improvement

Ø Analysis of failure history

Ø Calculation of key indicators: MTBF, MTTR, availability rate

Ø Revision of the maintenance plan based on feedback

Ø Update of electrical diagrams and procedures

11. Classification of planned maintenance of electrical equipment

Planned maintenance of electrical equipment is a set of pre-scheduled actions carried out with the aim of preventing breakdowns, ensuring safety, and maintaining the performance of electrical installations.

It is the opposite of corrective maintenance (unplanned maintenance following a breakdown).

11.1. Predictive maintenance

Based on advanced data analysis to predict failures before they occur. Use techniques like:

o Infrared thermography

o Vibration analysis

o Harmonic currents

o AI or statistical models (e.g., Weibull distribution)

Exemple

Examples:

Detection of abnormal heating in a transformer via thermal imaging camera, Wiring replacement before break detected by AI

11.2. Benefits of Planned Maintenance

- Reduced risk of breakdown
- Extended lifespan of electrical equipment
- Enhanced safety
- Compliance with standards
- Better budget predictability