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Department of electrical engineering



Educational handout

Industrial maintenance

Intended for 3rd year electrical engineering students.

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Lecturer “A”

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Preface

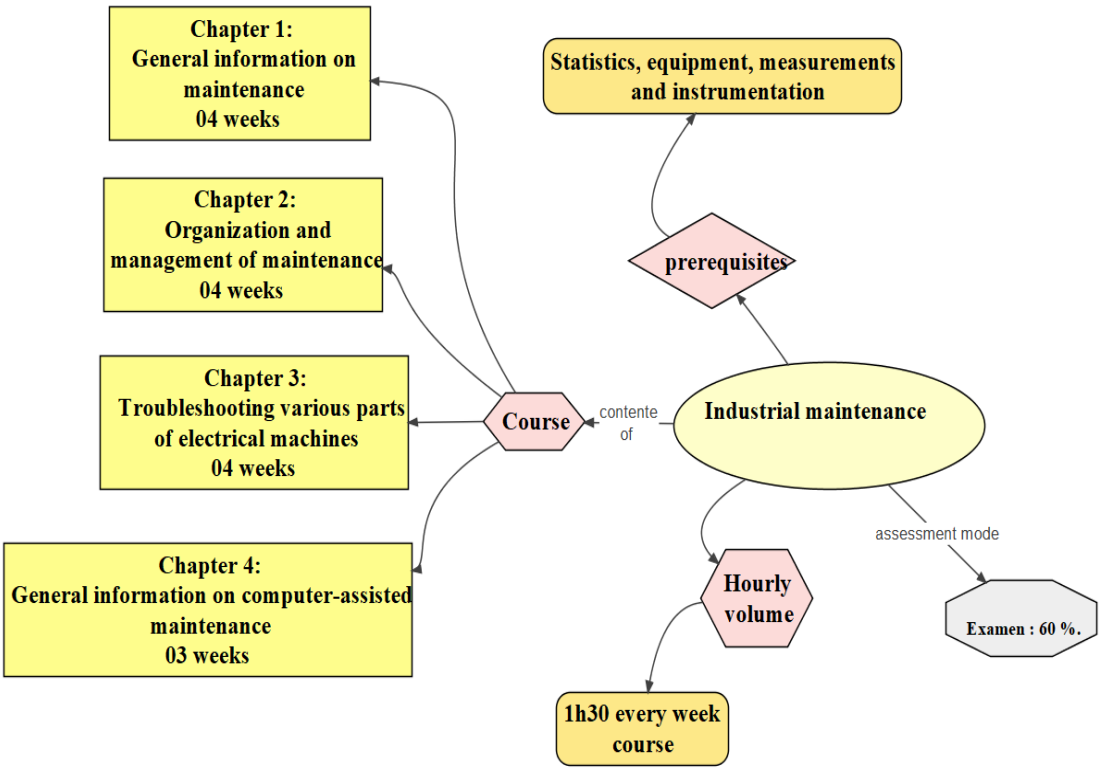
The growing role of maintenance in various industrial sectors, both small and large, requires technicians to work on increasingly varied equipment and to deepen their knowledge of all technologies. Additionally, with the growth of industrial companies and the increasing complexity and interconnection 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.

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Chapter 1:
General information on maintenance
04 weeks
Chapter 2:
Organization and management of maintenance
04 weeks
Chapter 3:
Troubleshooting various parts of electrical machines
04 weeks
Chapter 4:
General information on computer-assisted maintenance
03 weeks
Course
contente of
Industrial maintenance
Statistics, equipment, measurements and instrumentation
prerequisites
assessment mode
Hourly volume
1h30 every week course
Examen : 60 %.

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CHAPTER 1

General information on maintenance

1 Chapitre 1 : General information on maintenance

1.1 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.

1.2 The history and evolution of industrial maintenance

1.2.1 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.".

1.2.2 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.

1.2.3 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).

1.2.4 Emergence of modern maintenance (1980–2000)

- Implementation of advanced methodologies:
  - TPM (Total Productive Maintenance) – Japan, automotive industry.
  - RCM (Reliability-Centered Maintenance) – aeronautics sector.
- Enhanced terminology:
  - Predictive maintenance: based on real-world data (sensors, vibrations, thermography, etc.).
  - CMMS (Computerized Maintenance Management System): digitization of processes.
- Importants standards :

- NF X60-010 (France): maintenance terminology.
- Introduction of ISO 9000 standards with an "equipment control" component.

1.2.5 Smart and standardized maintenance (2000–present)

- Maintenance integrated into asset management:
  - ISO 55000 Standard (Asset Management)
- Predictive maintenance + artificial intelligence = prescriptive maintenance :
  - AI and IoT make it possible to anticipate breakdowns.
- Recent concepts:
  - Industry 4.0
  - Maintenance 4.0
  - Digital twins
- Standardized terminologies:
  - ISO 14224: reliability and data collection.
  - EN 13306: standardized maintenance terminology.

1.3 Concepts and Definitions

1.3.1 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.

1.3.2 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 maintenance is carried out under given conditions, using prescribed procedures and means."

1.3.3 Definition of Reliability

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

1.3.4 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

1.3.5 Concept of failure

1.3.5.1 ***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.

1.3.5.2 ***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.

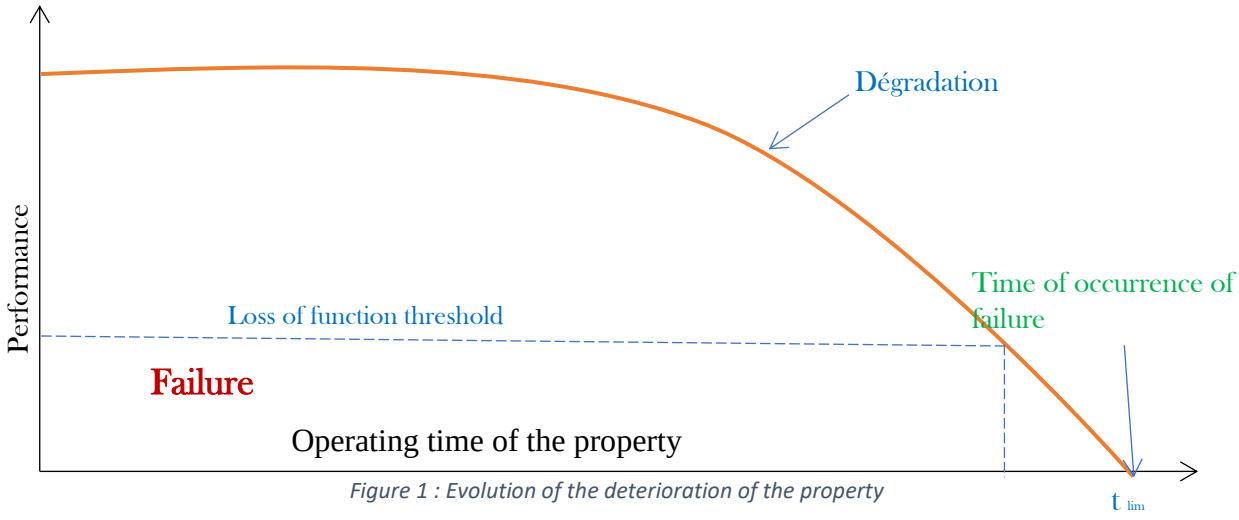


Figure 1 : Evolution of the deterioration of the property

1.4 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.

1.4.1 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

1.4.2 Role of troubleshooting in industry

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

1.4.3 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

1.5 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.

1.5.1 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).

1.5.2 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: $D = \frac{MTBF}{MTBF+MTTR}$.

And the failure rate (λ) which is calculated as follows: $\lambda = \frac{1}{\text{MTBF}}$

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

1.5.3 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).

1.5.4 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.

1.6 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

1.6.1 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 1:

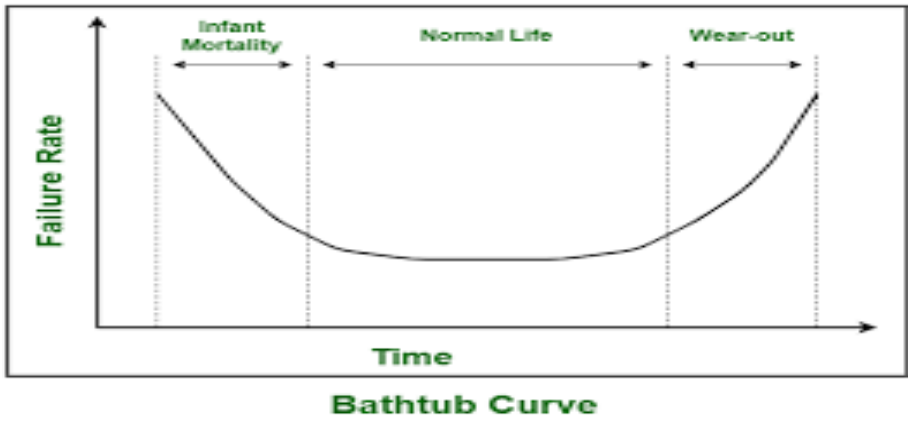


Figure 2 The Bathtub curve

Table 1 Explication of the Bathtub curve

Phase	Description	Failure rate

Youth (or running-in)	Commissioning period where manufacturing or assembly defects may appear	Decreasing
Useful life (or stable phase)	Normal operation, infrequent random failures	Low and stable
Aging (or wear)	Natural wear and tear, material fatigue, corrosion, obsolescence	Croissant

1.6.2 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

1.7 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.

1.7.1 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.

$$h(t) = \frac{f(t)}{R(t)} \quad (1)$$

f(t): probability density of failure

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

1.7.2 Reliability laws (statistical models of behavior over time)

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

1.7.2.1 *Exponential law*

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

$$R(t) = e^{-\lambda t} \quad (2)$$

λ: constant failure rate

MTBF = 1/λ

Example: electronic components without mechanical wear.

1.7.3 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:

$$R(t) = e^{-(\frac{t}{\eta})^{\beta}} \quad (3)$$

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.

1.7.4 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.

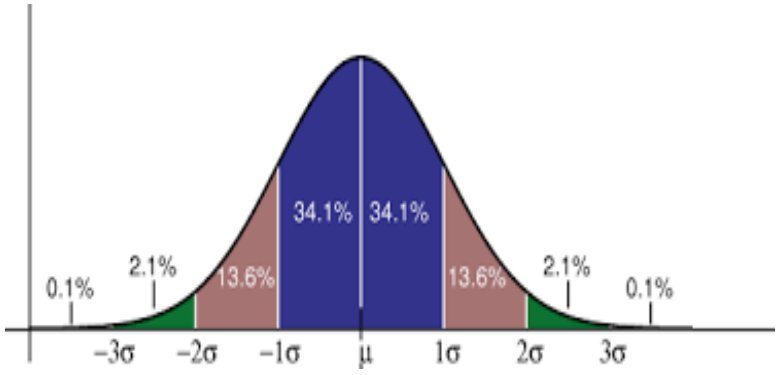


Figure 3 Normal (or Gaussian) law

1.8 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).

1.8.1 Reliability of a system consisting of several components

1.8.1.1 *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.

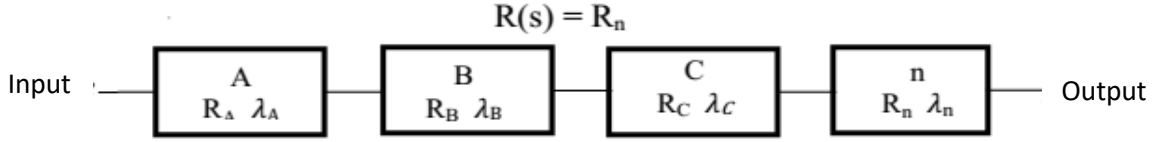


Figure 4 : Reliability of a system in series

$$R_S = R_A \times R_B \times R_C \dots \dots . R_n \quad (4)$$

$$R_S = \left(e^{-\lambda_A t}\right).\left(e^{-\lambda_B t}\right).\left(e^{-\lambda_C t}\right) \dots . . \left(e^{-\lambda_n t}\right) \quad (5)$$

With: $$MTBF_S = \frac{1}{\lambda_A+\lambda_B+\lambda_C \dots \dots \dots +\lambda_n} \quad (6)$$

If, in addition, the components are identical:

$$\lambda_A = \lambda_B = \lambda_c = \cdots = \lambda_n = \lambda$$

So: $$R_S = e^{-n\lambda t}$$

And: $$MTBF_S = \frac{1}{n\lambda}$$

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.

$R_S = R_A . R_B . R_C . R_D = 0.95 \times 0.92 \times 0.97 \times 0.89 = 0.7545$ (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**

$\lambda_A = \frac{1}{MTBF_A} = \frac{1}{4500} = 0.000222$ 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: $R_S(t) = e^{-\lambda_S t} = e^{-0.000797 \times 1500} = 0.303\ (30.3\%)$

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

$R_S(5000) = e^{-0.000797 \times 5000} = 0.0186\ (About\ 2\%)$

1.8.1.2 ***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:

$F_i = 1 - R_i$

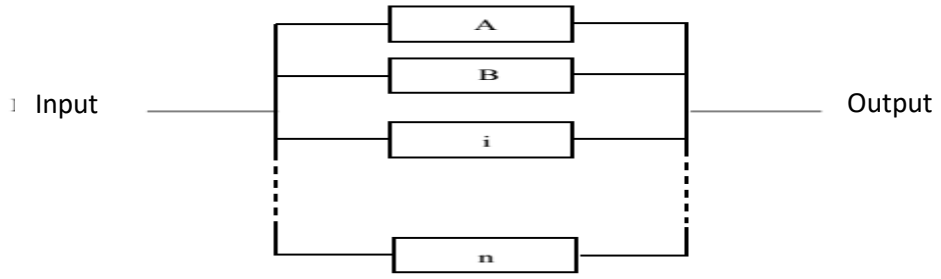


Figure 5 : Reliability of a system in parallel

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:

$$R(s) = 1 - (1 - R)^n \quad (5)$$

Example:

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

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

If we reduce the number of components to two

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

If we put four devices in parallel

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

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

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

$1 - (1 - 0.75)^n = 0.999 \implies$ n = 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?

$R(s) = 0.99 = 1 - (1 - R)^3 \implies$ R = 0.7846 A minimum reliability of 78.46%

1.8.1.3 ***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:

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

1.9 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.

1.9.1 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.

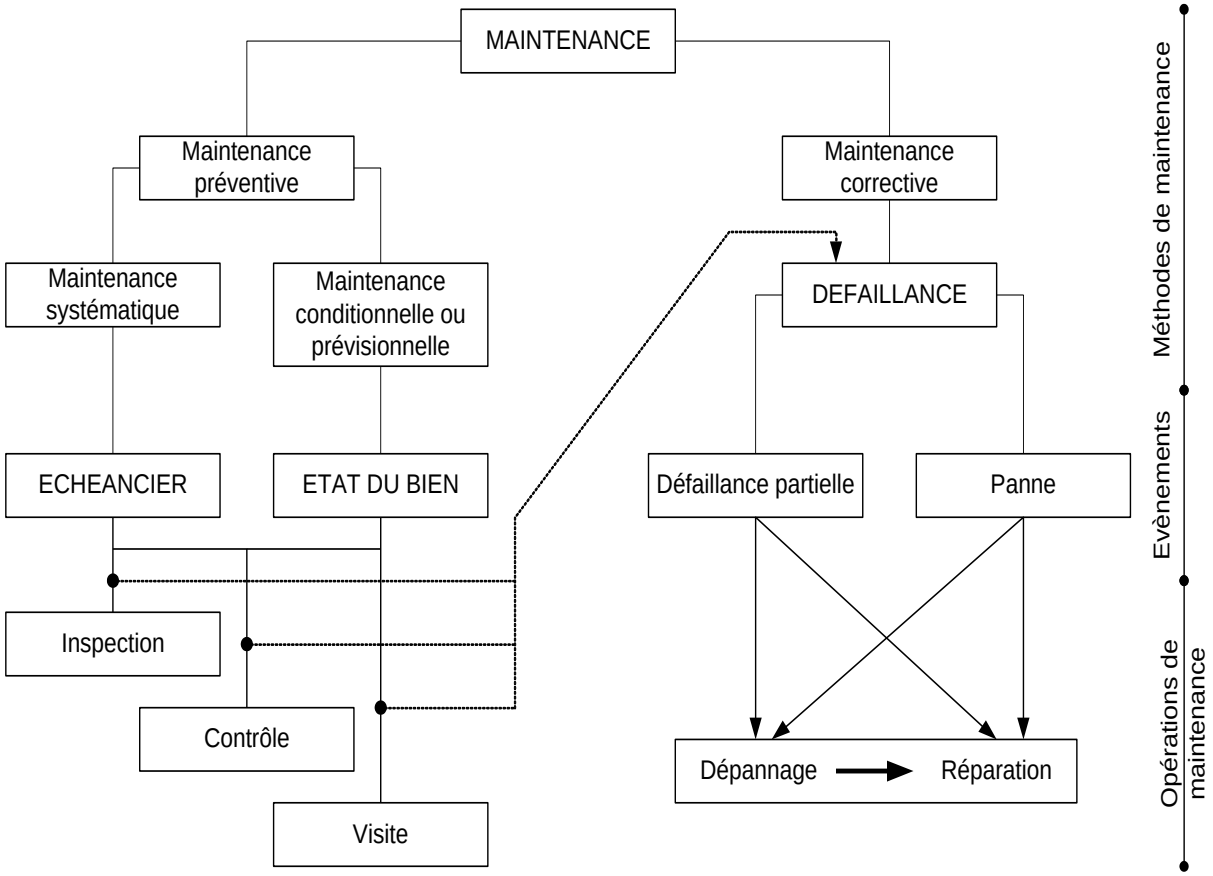


Figure 6 : The different forms of maintenance

1.9.2 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.

1.9.2.1 *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.

1.9.2.2 ***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.

1.9.3 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.

1.9.4 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.

1.9.5 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.

1.9.5.1 *Objectives of Improvative Maintenance*

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

1.10 Organization of maintenance and repair of electrical equipment

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

1.10.1 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.

1.10.2 Organization of electrical maintenance (preventive)

1.10.2.1 *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

1.10.2.2 ***Typical interventions***

Typical interventions are scheduled according to the following table:

Table 2 : Typical interventions

Equipment	Routine maintenance
Electrical panels	Tightening, cleaning, thermography
Circuit breakers / relays	Trigger test, visual inspection
Electric motors	Lubrication, insulation measurement
Cables / Connections	Warm-up control, continuity

1.10.3 Organization of electrical troubleshooting (corrective)

1.10.3.1 ***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

1.10.3.2 ***Resources needed***

- Team of trained electrical technicians (B0, H1, etc. accreditations)
- Spare equipment available (critical spare parts)
- Specialized tool kit

1.10.3.3 ***Priority criteria***

- Safety
- Impact on Production
- Estimated Downtime
- Parts Availability

1.10.4 Monitoring and continuous improvement

- Analysis of failure history
- Calculation of key indicators: MTBF, MTTR, availability rate

- Revision of the maintenance plan based on feedback
- Update of electrical diagrams and procedures

1.11 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).

1.11.1 Predictive maintenance

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

- Infrared thermography
- Vibration analysis
- Harmonic currents
- AI or statistical models (e.g., Weibull distribution)

Examples:

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

1.11.2 Benefits of Planned Maintenance

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

CHAPTER 2

Organization and management of maintenance

2 Chapter 2: Organization and management of maintenance

2.1 Introduction

The organization and management of maintenance encompass all activities, methods, and means implemented to ensure the proper functioning, durability, and safety of a company's equipment and installations.

2.2 Structure of workshops specializing in troubleshooting electromechanical converters

2.2.1 Definition

We define a maintenance workshop as a set of resources (technicians, intervention stations, tools, spare parts, magazines) intended to guarantee the longevity of production machines. Its role is to detect the origin of failures on a defective machine and to restore its operation (corrective maintenance).

An example of an organizational chart is given in Figure 2. This is only one possibility; each technical director is free to organize it according to their convictions. However, it does show functions that are essential for the maintenance function to be effective.

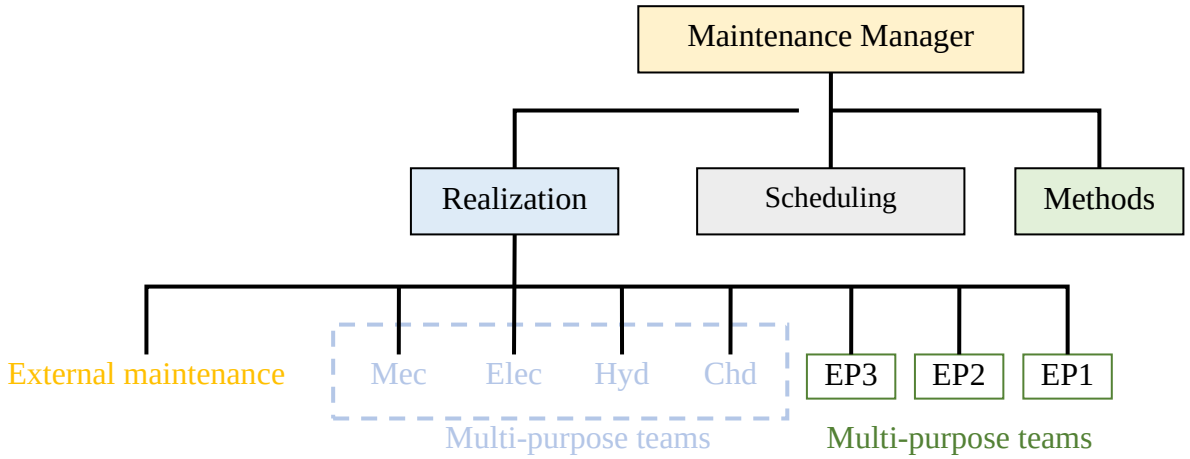


Figure 7 : Typical structure with partial sectorization

2.2.2 Realization function

The implementation team is multi-ethnic and has a composition adapted to the equipment. For example, it includes a team leader, an electrician, a mechanic, and a hydraulic engineer. It is responsible for carrying out maintenance tasks planned by the methods department.

The main tasks to fulfill this function are as follows:

- Install machines and equipment (reception, inspection, etc.);
- Inform staff on how to use equipment and perform upgrades;
- Apply health, safety, and working conditions guidelines;

- Manage maintenance scheduling and interventions and diagnose equipment failures;
- Coordinate maintenance interventions and restart equipment after intervention;
- Manage material resources (spare parts, tools, etc.).

2.2.3 Methods function

The methods function consists of optimizing all tasks based on the criteria selected when formulating the maintenance policy. This section combines four primary functions.

The first task, relating to the technical study as indicated in figure 8, consists of:

- □ Research improvements in the production system that are likely to provide the desired added value;
- □ Participate in the design of new projects while taking into account the maintenance aspect of the production equipment;
- □ Participate in the analysis of workplace accidents to try to remedy them by providing safety instructions first and corrective and preventive maintenance actions second.

The second task, relating to preparation and scheduling, consists of:

- □ Prepare the necessary instruction sheets to carry out interventions;
- □ Compile documentation for all types of interventions;
- □ Establish schedules for preventive and supply interventions (inventory management policy depends on the company's policy);
- □ Receive and file documents relating to the intervention.

The third task, relating to the economic and financial study, involves several stages such as:

- □ Manage procurement to optimize the management of raw materials required for the production process;
- □ Analyze maintenance, failure, and operating costs, which will have a direct impact on the maintenance policy chosen by the manufacturing company and also on production costs;
- □ Participate in the drafting of specifications to take into account the maintainability and reliability of the systems to be controlled;
- □ Manage the monitoring and execution of work to update the historical section of the machine technical file.

To fulfill the study and method function with all its components as mentioned above, the staff must have technical files summarizing the technical characteristics of the machines and wear parts; history sheets summarizing the operations already carried out, in other words, the

behavior of the machine; constantly updated supplier documentation summarizing the evolution of techniques and databases (possibly).

2.2.4 Scheduling function

The Scheduling function enables optimal intervention at the right time, utilizing all necessary resources, including personnel, tools, preparation, technical files, safety instructions, special equipment (such as lifting equipment and scaffolding), and spare parts.

2.2.4.1 *Role of scheduling in maintenance*

Scheduling represents the "conductor" function. In a maintenance department characterized by an extreme variety of tasks in terms of nature, duration, urgency, and criticality, the absence of a conductor quickly leads to cacophony, regardless of the brilliance of the soloists. Scheduling is located between the method function, which is responsible for defining the tasks to be performed and the means to be implemented, and the implementation function, which is responsible for their execution

The term "scheduling" is often replaced by the term "planning" in businesses. But for us, and according to standards, scheduling is planning that takes into account available resources and means.

2.2.4.2 *Scheduling missions*

Responsible for the management and synchronization of internal or outsourced maintenance actions, the scheduling function has the following mission:

- Plan the timeline for the various tasks;
- Optimize the necessary resources based on deadlines and critical paths;
- Adjust workloads to known capacities;
- Start work at the chosen time, making all necessary resources available;
- Monitor the progress and completion of work;
- Manage projects (forecasting, logistics optimization, progress, and compliance with deadlines);
- Analyze gaps between forecasts and actual results.

This can be expressed in the form: plan a time t and a place x where a staff member p, equipped with tools o and materials m, will carry out task M in harmony with other related work.

2.3 Conditions for the success of a maintenance management program

A maintenance management program cannot achieve the desired results without proper site preparation and staff involvement. These two conditions are essential for the success of a maintenance management system. Other conditions must also be added for the successful implementation of the system:

- Set a fixed objective: This objective will help outline the guidelines for the maintenance policy. It depends significantly on the company's mission. Take, for example, a hotel company seeking customer comfort. This cannot have the same maintenance department as a mining company seeking to reduce the cost per kilogram of ore;
- Foster motivated management and staff for the implementation of maintenance;
- Employ rigorous procedures for collecting, processing, and archiving relevant data. This data will be used in the maintenance management system;
- Ensure communication between the various team members;
- Establish procedures for monitoring, evaluating performance, and displaying performance indicators.

2.4 Stages of designing a maintenance workshop

The design of a maintenance workshop is a critical step in ensuring the functionality, efficiency, and safety of maintenance operations. Maintenance is, therefore, a key area of focus in the search for improved company performance. However, maintenance methods and techniques are not unique and universal. Depending on the type of industrial processes to be maintained and the nature of the systems, subsystems, or equipment, specific methods will need to be implemented, taking into account the technologies deployed in each case:

- dynamic mechanical systems: motors, pumps, etc.,
- programmed digital systems,
- hydraulic or thermohydraulic systems,
- electrical or electronic systems: sensors, programmable logic controllers.

In the process of designing a maintenance workshop, we distinguish three main phases:

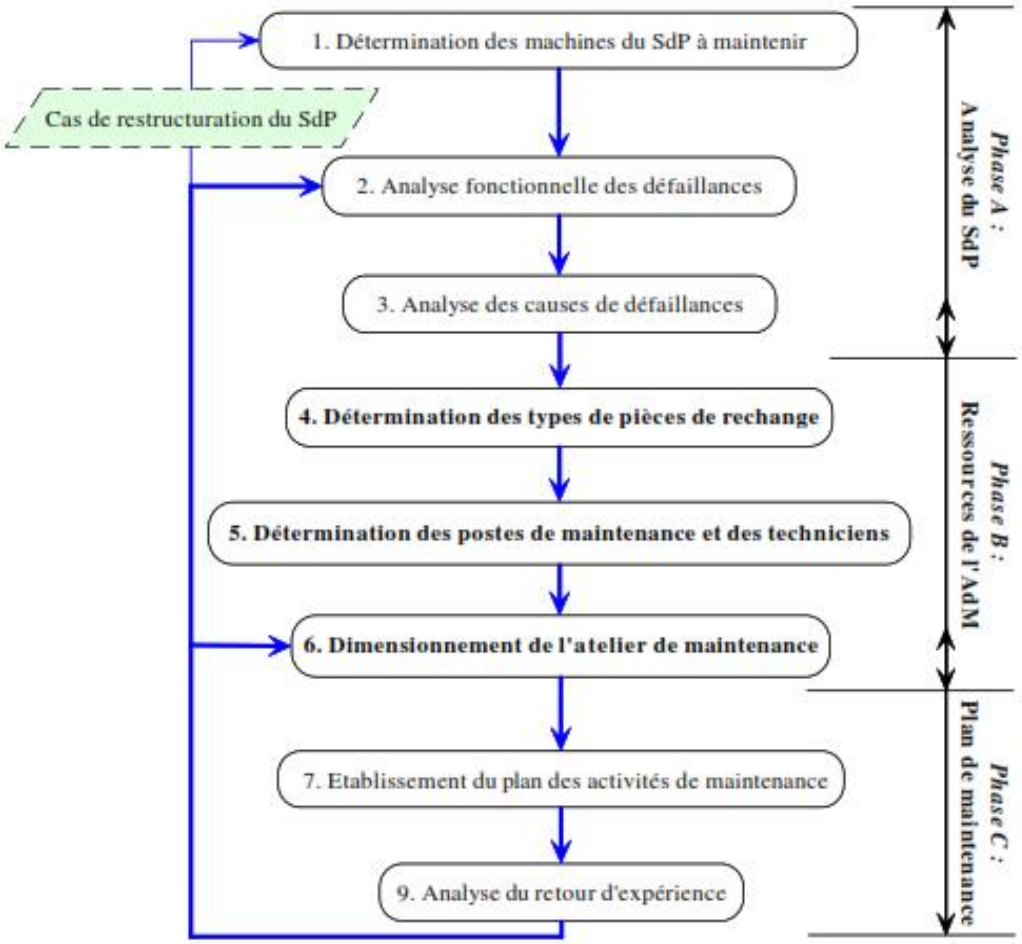


Figure 8 : Stages of designing a maintenance workshop

Sentence A: Analysis

This phase involves studying all production machines. Its purpose is to determine which machines should be prioritized for the study. Then, the functional failures of the selected machines are examined and linked to the shortcomings of the various equipment that compose them. These failures are analyzed from the point of view of failure mode, its possible causes, and its effects on the equipment's functions.

Phase B: Determination of maintenance workshop resources

In this phase, we qualitatively determine the resources that comprise the maintenance workshop, including intervention stations, technicians, and spare parts for replacement. The structural organization of the maintenance workshop is then defined.

Phase C: Maintenance Plan Development Phase

In this phase, the type of action that needs to be implemented for each piece of equipment is defined. This leads to the development of an initial schedule of the various maintenance tasks.

2.5 Organization of maintenance operations

Organizing maintenance operations is a crucial step in ensuring the efficiency, reliability, and durability of equipment and facilities. Here are the main aspects to consider when organizing maintenance operations:

1/ Strategic Planning:

- Define maintenance objectives aligned with the company's overall goals.
- Establish a maintenance strategy (preventive, corrective, predictive, etc.) based on the specific needs of the equipment and facilities.

2/ Organization of Resources:

- Allocate the necessary human, material, and financial resources to carry out maintenance activities efficiently and effectively.
- Determine the roles and responsibilities of maintenance personnel, including technicians, supervisors, and managers.

3/ Asset Management:

- Establish a comprehensive inventory of equipment and assets that require maintenance.
- Implement an asset management system to track their performance, maintenance history, and total cost of ownership.

4/ Planning of Interventions:

- Develop a preventive maintenance schedule to plan regular interventions based on the equipment's specific needs.
- Establish procedures to manage corrective maintenance requests responsively and efficiently.

5/ Inventory Management:

- Manage spare parts and supplies required for maintenance to avoid extended downtime.
- Implement an inventory management system to control stock levels, replenishment, and rotation.

6/ Documentation and Monitoring:

- Maintain accurate records of maintenance activities, including interventions performed, parts replaced, and associated costs.
- Use computerized maintenance management systems (CMMS) to automate documentation and facilitate activity tracking.

7/ Communication and Collaboration:

- Foster effective communication and collaboration among maintenance teams, operations, suppliers, and other key stakeholders.

- Establish clear communication channels to report issues, share knowledge, and coordinate activities.

2.6 Study of the various breakdowns of electrical machines

Studying the various breakdowns of electrical machines is essential for understanding the underlying causes of failures and implementing preventive measures to avoid their recurrence. Here is a table that covers the common breakdowns encountered in electrical machines.

Table 3 : the common breakdowns encountered in electrical machines

electrical machine failures	internal	mechanical	contact between the stator and the rotor
			bearing defects
			eccentricity
			movement of windings and sheets
		electric	insulation failure
			bar break
			magnetic circuit failure
	external	mechanical	oscillating load
			machine overload
			assembly defect
		environmental	humidity
			temperature
			cleanliness
		electric	voltage fluctuation
			sources of unbalanced tensions
			noisy network

2.6.1 Stator faults

- Short circuit between turns: overvoltage, excessive temperature, vibration, humidity.
- Short circuit between phases: high temperature, power supply imbalance, installation fault.
- Insulation fault: frequent starting, partial discharge, extreme conditions, and temperature and humidity fluctuations.
- Stator-frame fault: thermal cycling, insulation abrasion, winding fouling by the frame, presence of sharp points in the slots, shock.
- Conductor displacement: frequent starting, coil head vibration.
- Connector failure: excessive vibration.
- Frame vibration: improper installation, magnetic imbalance, power supply imbalance, overload, winding movement, contact with the rotor.

2.6.2 Rotor defects

- Bearing failure: improper installation, magnetic imbalance, high temperature, lubricant loss, unbalanced load, corrosion.

- Bar failure: thermal cycling, long-term transient conditions, magnetic imbalance.
- Ring failure: thermal cycling.
- Eccentricity: improper installation, magnetic imbalance, bearing failure.
- Bearing misalignment: coupling fault, improper installation, overload.
- Magnetic circuit failure: manufacturing defect, overload, thermal cycling.
- Mechanical imbalance: misalignment, short-circuit ring movement.

2.6.2.1 *Bearing defects*

- The majority of faults in electrical machines involve bearing defects, which have numerous causes, such as fatigue spalling, lubricant contamination, excessive load, or electrical causes, such as the flow of leakage currents induced by inverters.
- Bearing defects typically produce several mechanical effects in machines, including increased noise levels and the appearance of vibrations due to rotor movement around the machine's longitudinal axis. This type of fault also induces variations (oscillations) in the load torque of the asynchronous machine.
- The ultimate point of bearing failure is the rotor lock.

2.6.2.2 *Eccentricity*

The consequences of mechanical defects generally manifest themselves at the air gap through eccentricity defects. The eccentricity of an electrical machine is a phenomenon that evolves and exists from its manufacturing stage. This process involves various machining and assembly steps that cause the rotor to be decenter relative to the stator.

Three categories of eccentricity are generally distinguished:

- **Static eccentricity** – generally due to a misalignment of the rotor's rotational axis relative to the stator's axis. The leading cause is a centering defect of the flanges.
- **Dynamic eccentricity** – corresponds to a rotor rotation center different from the geometric center of the stator, but, in addition, the rotor center rotates around the geometric center of the stator [24]. This type of eccentricity is caused by deformation of the rotor cylinder, the stator cylinder, or damage to the ball bearings.
- **Mixed eccentricity** – the sum of the two cases presented above

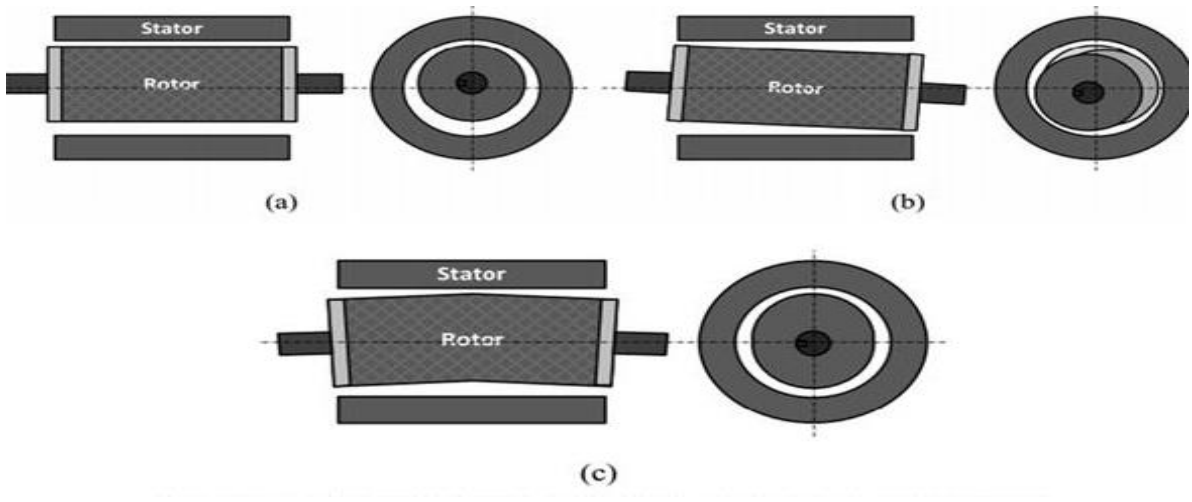


Figure 9 : Eccentricity defects

2.6.2.3 *Busbar and short-circuit ring break faults*

The same faults as in the stator can be found in a wound rotor. For an asynchronous machine with a squirrel-cage rotor, faults are limited to broken bars or broken short-circuit rings.

Breakages of bars or ring sections can be caused, for example, by mechanical overload (such as frequent starts), excessive local heating, or a manufacturing defect (such as air bubbles or poor welding). This causes oscillations in the currents and electromagnetic torque, which are more pronounced when the inertia is very high (constant speed).

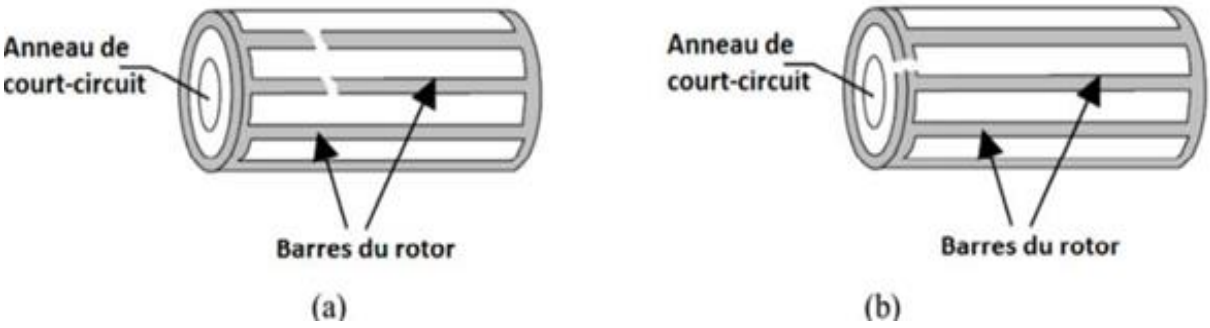


Figure 10 : Bar break and short-circuit ring faults

2.7 Methods for detecting faults in electrical machines

To detect electrical machine faults early and effectively, several monitoring and diagnostic methods and techniques are used.

2.7.1 Methods of knowledge

Knowledge methods do not use a mathematical model to describe cause-and-effect relationships. Knowledge is based solely on human experience, supported by feedback.

2.7.2 Analytical redundancy methods

Based on quantitative modeling of the system and exploiting the relationships between the variables of the system considered to identify the physical parameters to monitor.

2.7.3 Signal modeling methods

These are methods based on signal modeling, spectral content, variance, and time evolution of the measured variables. These methods mainly exploit electrical, magnetic, vibrational, thermal signatures, or instantaneous power.

2.8 Disassembly and reassembly technique

Disassembling a mechanism is often necessary for diagnosis, troubleshooting, or repair. A disassembly phase must be organized so that the maintenance technician performs a minimal amount of disassembly relative to the need for it, which avoids:

- □ Loss of time
- □ Risk of component damage

In maintenance, disassembly can be classified into two categories:

- □ Total disassembly during a complete overhaul of an installation.
- □ Partial or targeted disassembly to replace a defective component.

2.8.1 Disassembly methodology

1. Study the assembly drawing.
2. Locate the component to be disassembled in the case of partial disassembly.
3. Locate the connecting elements (screws, etc.).
4. Identify the independent subassemblies.
5. Identify the position of the parts during disassembly, if necessary.
6. Use the appropriate tools.

2.8.2 Disassembly vocabulary

Safety: Familiarize yourself with and apply the procedures for locking out or securing people and property:

- □ Affix the STOP MAINTENANCE sign.
- □ Lock out the system (padlocks, disconnect switches).
- □ Purge the system (compressed air, oil).
- □ Neutralize movement by locking the transmission systems (belts, chains, couplings).

Drain: Empty the contents of a mechanism of used lubricating products (oil, grease).

Clean: Remove impurities to allow examination of components or subassemblies and facilitate handling.

Mark: Mark the position of components with light center punches before disassembly or removal.

Unscrew: Use a disassembly tool to free a component (usually a threaded component, screw, or nut) without removing it.

Remove: Remove and place a component or subassembly on a support.

Unscrew: Remove a threaded component from a mechanism.

Drive: Push a component or subassembly out of its housing using a suitable tool.

Extract: The action of using an extractor.

2.8.3 Reassembly Vocabulary

Reassembly work: This complementary phase to disassembly can be prepared following the same principle by searching for prior works.

Engage: Replace a component or subassembly on a shaft or in a housing.

Screw: Operate a threaded element to bring it into contact with another part of the mechanism without locking it (Adjustment).

Screw: Lock - Bring the threaded element into contact with another part of the mechanism and immobilize it to break it (Tightening torque).

Refill: Introduce new lubricant into the mechanism in accordance with the specifications and quantities recommended by the manufacturer.

Refit: Replace a subassembly in the position it occupied before removal.

Adjust: Fine-tune the operation of an assembly or subassembly.

Test: Operate the assembly or subassembly to perfect the adjustments to ensure the system's performance.

Control: Check or Measure performance to ensure the conformity of an item (Spare Part).

2.8.4 MARKING before dismantling

Before any disassembly, it is essential to mark the motor so that it can be reassembled as it was before disassembly. There are two main criteria to follow:

The direction of the stator frame

- The "pulley" side
- The "fan" side

The mounting of the end plates

- Sometimes, the mounting brackets are not equidistant from each other

Note: The marking on the fan side must be done once the cover is removed. It is also possible to mark the motor with a drawing on paper, which has the advantage of not "dirtying" the motor, especially if the motor is not standard and has a specific mounting.

2.8.5 Testing and diagnostics before troubleshooting

Before troubleshooting electric motors, it is crucial to perform testing and diagnostics to identify the source of the problem correctly.

2.8.5.1 *Before dismantling*

A. **Sensory controls:** Sensory testing is an inspection method that uses the human senses to detect anomalies or problems in a process or equipment, see Figure 11.

1. **Visual Inspection:** It is the use of sight to visually examine equipment, components, or products to detect any signs of damage, defects, or abnormalities.
2. **Listening:** Listening carefully to the sounds made by machinery or equipment can reveal unusual sounds, such as clicking, grinding, rubbing, or excessive vibration, which could indicate mechanical problems.
3. **Touch:** Touch can be used to detect temperature variations, vibrations, surface defects, or fluid leaks, which could indicate operational or safety issues.
4. **Olfaction:** Smell can be used to detect unusual odors or dangerous gases that could indicate leaks, electrical fires, or other problems.
5. **Taste**: (in certain particular and controlled cases): In specific situations, such as when detecting certain chemical substances, taste can be used to detect anomalies or contamination.
6. **Color Observation:** Visual perception of changes in color or shade may reveal variations or anomalies in materials or products.
7. **Observation of movements:** Observing the movements of equipment, parts, or products can help identify irregularities in operation, such as jerky movements, sudden stops, or oscillations.
8. **Observation of sparks or electric arcs:** In electrical equipment, the observation of sparks or electric arcs can indicate problems with insulation, short circuits, or component wear.



Figure 11 : Sensory checks before dismantling an electric motor

B. **Electrical control:** Electrical testing of an electric motor involves the use of various tools and methods to evaluate the electrical operation of the motor and identify potential problems. Here are some of the techniques commonly used for electrical testing of an electric motor:

1. **Voltage and Current Measurement:** Use a multimeter to measure the motor's supply voltage and the current flowing through the motor windings. Compare these measurements to the motor's specifications to verify that it is operating within normal limits.
2. **Continuity Test:** Use an ohmmeter to check the continuity of the motor windings. Ensure there are no short circuits or opens in the windings.

   Equipment Used: Ohmmeter calibrated on a small scale (200 Ω).

   Expected Results:

   Resistance ≠ 0 Ω,

   Resistance ≠ ∝,

   Identical resistances on all three windings.

   Zero resistance indicates a short circuit.

   Infinite resistance indicates an open winding.

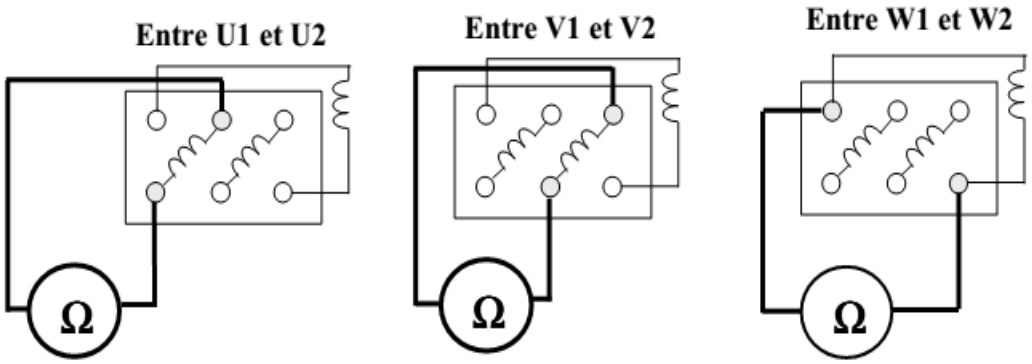


Figure 12 : Continuity Test

C. **Checking the insulation of the windings between them:** Use a megohmmeter to measure the motor's insulation resistance between the windings and the ground. Ensure it is high enough to ensure adequate insulation.

Equipment used: ohmmeter calibrated to a large scale (1 MΩ).

Expected results: very high resistance exceeding the scale (here R ≥1 MΩ) for all three measurements.

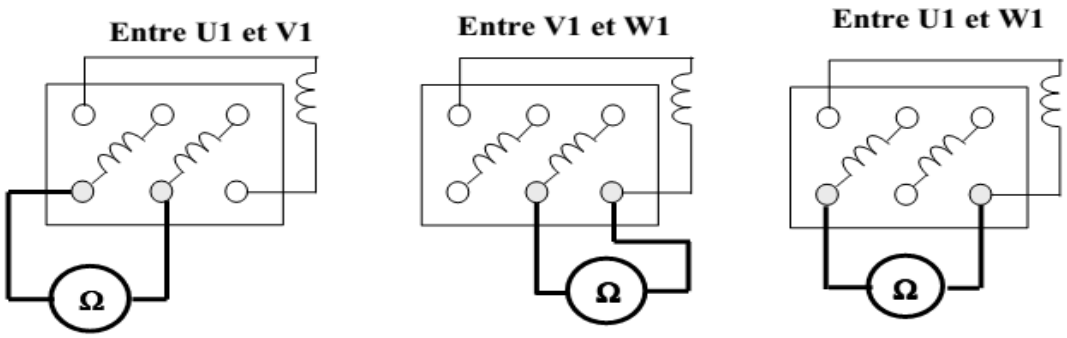


Figure 13 : Checking the insulation of the windings between them

D. **Rotation Test:** Apply a test voltage to the motor to rotate it. Check that the motor starts and rotates in the intended direction without excessive noise or abnormal vibration.

E. **Overload Test:** Apply a mechanical load to the motor and monitor its operating current. Check that the motor can withstand the rated load without overheating or overcurrent.

F. **Start and Stop Test:** Test the engine to ensure it starts and stops properly in response to start and stop commands.

G. **Inspection of protective devices:** Check the proper functioning of protective devices such as thermal relays, fuses, circuit breakers, etc. Make sure they are not tripped and are functioning correctly.

H. **Temperature measurement:** Use an infrared thermometer or temperature sensors to monitor the engine temperature while it is running. Ensure it remains within normal limits to avoid overheating.

CHAPITRE 3

Troubleshooting various parts of electrical machines

3 Chapter 3: Troubleshooting various parts of electrical machines

3.1 Introduction :

Troubleshooting electrical machines is an essential activity in industry and technical installations. It involves identifying, locating, and correcting faults in different types of electrical machines, such as motors, transformers, and alternators.

3.2 Troubleshooting the mechanical part

Troubleshooting the mechanical side of electrical machines is just as important as the electrical side. A mechanical failure can cause significant malfunctions or even severe damage to the machine. Here's a structured guide to diagnosing and correcting mechanical problems in electrical machines (motors, alternators, cooled transformers, etc.).

3.2.1 Mechanical components to be inspected

a) Bearings:
   - Defects: Wear, noise, excessive play, seizure
   - Tests:
     - Manually turn the shaft (while stationary)
     - Listen with a mechanical stethoscope
     - Vibration analysis

b) Drive shaft:
   - Defects: Runout, breakage, wear at the bearings
   - Checks:
     - Runout (dial gauge)
     - Alignment with the driven element (laser or ruler)

c) Rotor balancing
   - Symptoms: Cyclic vibrations, asymmetric wear
   - Action: Dynamic or static balancing

d) Couplings and pulleys:
   - Defects: Looseness, wear, misalignment
   - Inspection:
     - Visual condition
     - Laser alignment
     - Tightness check

e) Fan / Cooling System:

- Faults: Broken fins, obstruction
- Effects: Engine overheating
- Regular cleaning required

3.2.2 Mechanical troubleshooting procedure

Here is a detailed table that summarizes the different mechanical troubleshooting procedures.

Table 4 : Mechanical troubleshooting procedure

Nbre	Stage	Description
1	Initial observation	Listen, feel, observe the machine's behavior
2	Safe stop	Turn off the power, secure the environment
3	Manual rotation	Test the smoothness of the rotation
4	Visual inspection	Search for broken, loose, worn parts
5	Technical measures	Alignment, runout, axial/radial play
6	Lubrication	Check oil or grease, level and quality
7	Empty test	After repair, observe the empty behavior
8	Load test	Revalidate under real load

3.3 Troubleshooting the electrical part

3.3.1 Steps of Electrical Troubleshooting

- Step 1: Check the power supply
  - Voltage at the supply terminals (ph-ph and ph-neutral)
  - Check fuses, circuit breakers, and switches
  - Check the phase sequence (three-phase)
- Step 2: Control Circuit Inspection
  - Checking contacts (buttons, relays, contactors)
  - Checking control wire continuity
  - Checking timers and safety devices (limit switches, emergency stops)
- Step 3: Test the Windings
  - Measuring winding resistance with a multimeter
  - Comparing the three phases (symmetry)
  - Detecting internal short circuits or breaks
- Step 4: Measuring the insulation
  - Test between windings and ground (earth)
  - Acceptable value >1 MΩ (generally)
  - Clean or dry if insulation is low

- Step 5: Checking the protections
  - Circuit breakers and thermal relays: are they properly sized?
  - Status of safety contacts (NO/NC)
  - Operation of thermal or electronic protection systems
- Step 6: Checking the accessories
  - Capacitors (single-phase or starter): check capacity and condition
  - Sensors: voltage, temperature, position, current
  - Regulator (AVR, inverter): integrated diagnostics, fault indicators

3.3.2 Critical points to inspect by machine type

- Mo Winding resistance (U-V-W)
  - Phase balance control
  - Insulation resistance tors (asynchronous or direct current)
- Transformers
  - Input/output voltage
  - Iron/copper losses (no-load/load)
  - Heating, oil leakage
- Alternators / generators
  - Excitation Check
  - Output Voltage, Stability
  - Voltage Regulator Check

3.4 Assembly work after repair

Assembly work involves installing, reconnecting and aligning all mechanical and electrical components after maintenance or repair work.

3.4.1 Main steps:

A. Preparation
   - Checking the spare parts used
   - Cleaning surfaces (contacts, supports)
   - Checking the conformity of the electrical/mechanical diagram

B. Mechanical assembly
   - Alignment of shafts and couplings
   - Tightening of bolts to the required torque, according to standards
   - Checking clearances (bearings, shafts)
   - Assembly of mechanical protections and casings

C. Electrical assembly

- Connecting the power cables (phases, ground)
- Tightening the terminals (check the recommended torque)
- Checking the control wiring (relays, contactors)
- Connecting any sensors or actuators, if present

3.4.2 Post-troubleshooting test methods

Testing helps validate that the system is working correctly and meets safety and performance standards. The following table gives the tests to be carried out (recommended order)

Table 5 : The tests to be carried out (recommended order)

Essay	**Aim**	**Tools / Methods**
Continuity test	Check connections, closed loops	Multimeter
Isolation test	Detect current leaks, weak insulation	Megohmmeter (≥ 1 MΩ recommended)
Direction of rotation	Check that the engine is turning in the correct direction	Short power-up (pulse)
Phase test / balancing	Avoid overload and imbalance	Current clamp / voltmeter
Voltage and current measurement	Confirm compliance	Multimeter / Network Analyzer
Thermal test	Identify abnormal heating	Thermal camera or infrared thermometer
Empty test	Observe engine behavior without load	Visual surveillance + instruments
Load test	Check actual operation	Test under normal conditions

3.4.3 Documents to be produced after testing

Table 6 summarizes the various documents to be completed after testing.

Table 6 : Documents to be produced after testing

Document	**Content**
Test reports	Measured values, observations
Recommissioning sheet	Date, operator, final remarks
Final state photos	Connections, junction boxes, labeling
Quality control sheet	Conforms/non-conforms, comments

3.5 Possible causes of failures and corresponding checks

Here is a list of possible causes of breakdowns in electrical machines, along with the corresponding checks that can be performed to detect these problems:

Table fatma

Chapitre 4 : General information on computer-assisted maintenance

4 Chapitre 4 : General information on computer-assisted maintenance

4.1 Introduction :

By definition, CMMS is software that allows you to plan, manage, track, and optimize preventive, corrective, and predictive maintenance activities for a fleet of machines or facilities. It is used in various industries, including the service sector, hospitals, transportation, and more.

4.2 The different functional modules of a CMMS

CMMS software is generally divided into modules. Each user can purchase the ones they deem necessary in order to work "leanly" and fully exploit their investment. The following list shows the modules found in the majority of CMMS on the market. It is not exhaustive and the names may vary from one software package to another. These include:

4.2.1 "Equipment management" module:

This involves describing and coding the breakdown tree structure ranging from the entire fleet to be maintained to the equipment identified and characterized by their DTE (technical equipment file) and their history, then to their own functional breakdown.

4.2.2 "Operational equipment monitoring management" module

This module will allow you to monitor the performance of equipment based on reliability, maintainability, and availability indicators.

4.2.3 "Intervention management" module

This module should allow rapid recording of the duration, location, and nature of an intervention.

4.2.4 "Preventive management" module

This module must allow systematic maintenance to be managed through a calendar schedule per piece of equipment, and the dates must be determined from a meter reading (or a measurement in the case of conditional maintenance). This means that the triggering will be automatic, by a weekly listing of the operations planned for the week. Each operation will be scheduled by its preventive range.

4.2.5 "Inventory management" module

The system is based on the file of items in the store, including the "maintenance batches" by equipment and on the movements in and out of the store.

4.2.6 "Supply and Purchasing Management" Module

The maintenance function is characterized by a large number of references and suppliers for small quantities and short lead times. This module must allow for purchasing management.

4.2.7 "Failure Analysis" Module

The basis of this module is made up of the history automatically populated by each WO (work order) or WO (work order) entry. This allows for a quantitative or qualitative analysis of failures.

4.2.8 "Budget and Expense Tracking" Module

The objective of this module is to monitor the evolution of expenses by activity within a given budget.

4.2.9 "Human Resources Management" Module

Specifically adapted to the maintenance department, this module will mainly be an aid to scheduling.

4.2.10 "Dashboards and statistics" module

Dashboards concerning the formatting of all technical, economic, and social indicators selected to ensure the management of the maintenance service.

4.3 What is a CMMS for?

The primary objective of maintenance has long been to reduce equipment downtime. Today, maintenance managers are required to manage a range of parameters that have a direct impact on equipment reliability, operating costs, and the quality of products and services.

They must therefore at all times:

1. Control installation costs and understand the financial impact of their decisions
2. Control interventions, schedules, and their costs
3. Optimize human and technical resources
4. Optimize spare parts inventories
5. Have detailed knowledge of technical installations and maintain documentation

Furthermore, the sophistication of the technologies to be maintained leads to specialized personnel, divided into maintenance agents, field technicians, methods specialists, and more.

All these reasons contribute to the use of dedicated and communicative IT: a tool at the service of stakeholders and decision-makers. A true repository of knowledge and expertise for the maintenance department, this tool is capable of importing and exporting data to purchasing, accounting, and quality.

4.3.1 A CMMS must allow, at a minimum, the management of:

1. Technical Reference: The equipment description, organized by function in a tree structure, includes the information necessary for maintenance operations and analysis.
2. Maintenance Work: Work is tracked by technical reports entered and used differently depending on the user.
3. Maintenance Work Planning: Whether preventive or curative, maintenance requires operational planning and an intervention methodology.
4. Procurement and Inventory: A good strategy for procuring maintenance items and streamlining their use allows for significant savings while improving the overall reliability of the production facility.

4.3.2 The benefits obtained when implementing a CMMS are:

1. Reduced labor, spare parts, and administrative processing costs
2. Improved equipment reliability and availability
3. Better cost management, budget preparation, and assistance with calls for tenders
4. Improved maintenance work history
5. Improved intervention planning, search for the optimal preventive/corrective ratio based on the industry
6. Improved inventory management

4.4 Implementation of a CMMS

Certainly, various paths are possible. However, forgetting certain steps can lead to irremediable failure. Here are three of them:

1. **Development of specifications by establishing a multidisciplinary group**. Consultation of suppliers and review of references and the entire environment.
2. **Selection of the CMMS tool and its necessary modules**. Based on a well-defined problem, the answer is assumed to be straightforward. The software selection will be made after a detailed call for tenders and testing of the selected products.
3. **Appointment of an internal CMMS project manager**: this is the crucial step. The role of this project manager is indeed multiple: preparing people and methods for the software package's arrival, involving the relevant management, organizing technical support, overseeing budgets, and preparing databases.
4. **User consultation and training**: At all levels, users expect the CMMS to assist them in their work with minimal constraints.

4.5 Sectors of activity concerned

All sectors of activity that have assets to maintain are interested in using a CMMS tool. These include:

1. Industry (manufacturing, automotive, pharmaceuticals, etc.)
2. Energy (gas, oil, electricity, etc.)
3. Transportation (road, rail, air, etc.)
4. Medical (hospitals)
5. Real estate (social housing, rental housing, corporate and headquarters, general resources, etc.)
6. Etc.

4.6 CMMS software

4.6.1 Historical

- Appearing in the 1980s, the first CMMS software packages were designed to meet the needs of the industry. They subsequently found applications in other sectors, such as hospitals (medical device maintenance) and transportation (road and rail network maintenance).
- To meet these new targets, some CMMS vendors offered solutions specialized in specific business areas.
- At the same time, CMMS software packages were enriched with new features beyond the strict framework of maintenance (regulatory management, plan management, consumption monitoring, etc.). Since 2008, most of the global leaders in the CMMS market have been acquired by generalist vendors (particularly ERP vendors) in order to expand their offerings or conquer the market.

4.6.2 Some major general publishers in CMMS

Table 7 shows some of the main general CMMS publishers

Table 7 : Some major general publishers in CMMS

Publisher name	**Distributed software**
IBM	Maximo asset management
Infor global solution	Infor EAM
Apave	Mainta
GE Healthcare	AssetPlus
Isilog	IWS
Kimoce	Kimoce asset management
KPF Groupe	OPTIMa
Ventyx	Asset suite
Sphinx Manager	Sphinx manager
IfmH	Qb7

ACF Maintenance	Maintexpress
TPM Assistance	SyGmo

4.7 Benefits Observed

Here is a table that shows the interest of CMMS.

Table 8 : The benefits of a GMAO

Before CMMS	**After CMMS**
Unplanned downtime: 12 hrs/month	Reduced to 4 hrs/month
Maintenance cost/month: $9,000	Reduced to $6,500
Preventive tasks completed: 60%	Increased to 95%
Asset availability: 85%	Increased to 97%

4.8 Example of concrete application: production plant

An industry composed of

- 3 production lines
- 100 critical pieces of equipment
- 6 technicians

With CMMS:

- A compressor is programmed to be changed every 1,000 hours.
- The CMMS automatically generates a work order.
- The technician receives it on their mobile app.
- They perform the task, enter the parts used, take a photo, and close the job.
- The data is recorded in the machine's history.

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