People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

Ziane Achour University of Djelfa

Faculty of Sciences and Technology

Department of electrical Engineering

Course Handout
Industrial Maintenance

Course Intended for L3 Electrotechnics,

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General Introduction :

The increasing complexity and cost of production equipment have led to a significant rise in their usage intensity, highlighting the need for effective maintenance to ensure optimal performance of installations and machinery. Maintaining production equipment is a key issue for factory productivity as well as for product quality. This industrial challenge requires a reassessment of current rigid structures and the promotion of methods adapted to the evolving nature of equipment.

Any sector of activity that needs to maintain a continuous level of production or service activity. Today, companies can no longer neglect the upkeep of their production equipment. They are becoming aware of the economic stakes and are including maintenance in their investment decisions. Maintenance is considered a source of optimization for production equipment and even a driver of profit.

The maintenance of industrial systems has become an essential point during their design and operation, both for reasons of safety and operational reliability, and for reasons of profitability. Inadequate maintenance for a system can lead to critical situations, posing dangers to people, equipment, and the environment.

Maintenance isn't always about being able to restart faulty equipment; it's about mastering that equipment to the point of creating a maintenance schedule. This function should be a means of optimizing downtime and reducing production losses.

The purpose of this handout is to provide students with a means to strengthen their knowledge of Maintenance. Through this material, students will gain knowledge of the role of maintenance in the company; its organization, as well as its various objectives; they will also be able to perform calculations related to reliability.

This course will be divided into five chapters, structured as follows:

Chapter I: Generalities of Maintenance.

Chapter II: Maintenance Strategies.

Chapter III: Organization and Management of Maintenance.

Chapter IV: Troubleshooting the different parts of electrical machines.

Chapter V: General information on computer-aided maintenance (CAM).

CHAPTER I

GENERAL INFORMATION ON MAINTENANCE

1. Definition of maintenance :

Maintaining production equipment is a key issue for both factory productivity and product quality. It is an industrial challenge that requires questioning current rigid structures and promoting methods adapted to the new nature of the equipment.

Any sector of activity that needs to maintain a continuous level of production or service activity. Today, companies can no longer neglect the upkeep of their production equipment. They are becoming aware of the economic stakes and are including maintenance in their investment decisions. Maintenance is considered a source of optimization of the production tool and even a factor in profits.

According to AFNOR (NF X 60-010) :

Maintenance is a set of actions that allow an asset to be maintained or restored to a specified condition or to be able to provide a defined service. Effective maintenance means carrying out these operations at the optimal cost.

Comments: :

- **Maintain**: contains the notion of "prevention" on a system in operation.
- **Re-establish**: contains the notion of "correction" following a loss of function.
- **Specified state or defined service**: implies the predetermination of an objective to be achieved, with quantification of characteristic levels.
- **Optimal cost** that governs all operations with a focus on efficiency.

2. Maintenance or upkeep :

- **Maintain(Entretenir)** means troubleshooting and repairing equipment to ensure continuous production; Maintain means dealing with the equipment.

- **Maintaining (Maintenir)** means choosing the means to prevent, correct, or renovate according to the equipment's use and its economic criticality, in order to optimize the overall cost of ownership. Maintaining means controlling.

Actually, most " traditional entretien " services are shifting towards maintenance.

3. The maintenance service :

3.1. Situation within the company :

There are two trends regarding the positioning of maintenance within the company:

- **Tendency 1** :

Centralization where all maintenance is handled by a single service.

Hence the advantages are:

- ✓ Standardization of methods, procedures and means of communication.
- ✓ The possibility of investing in expensive equipment through group purchasing.
- ✓ Overall view of the state of the equipment fleet to be managed.
- ✓ Easier and more flexible management of personnel resources.
- ✓ Streamlining of material resources and optimization of their use (faster depreciation).
- ✓ Reduction in the quantity of spare parts available.
- ✓ Simplified communication with other departments thanks to its centralized location.

- **Tendency 2** :

Decentralization, where maintenance is entrusted to several services, proportionally smaller in size, and linked to each of the company's services.

Hence the advantages are:

- ✓ Improved communication and relationships with the responsible department and park users must be maintained.
- ✓ Fewer staff in the various branches.
- ✓ Increased responsiveness to problems.
- ✓ Improved knowledge of the equipment.
- ✓ Simplified administrative tasks.

Organizational chart of the maintenance department:

This is a schematic representation of the structure of a company (or department) highlighting the areas of responsibility of each component.

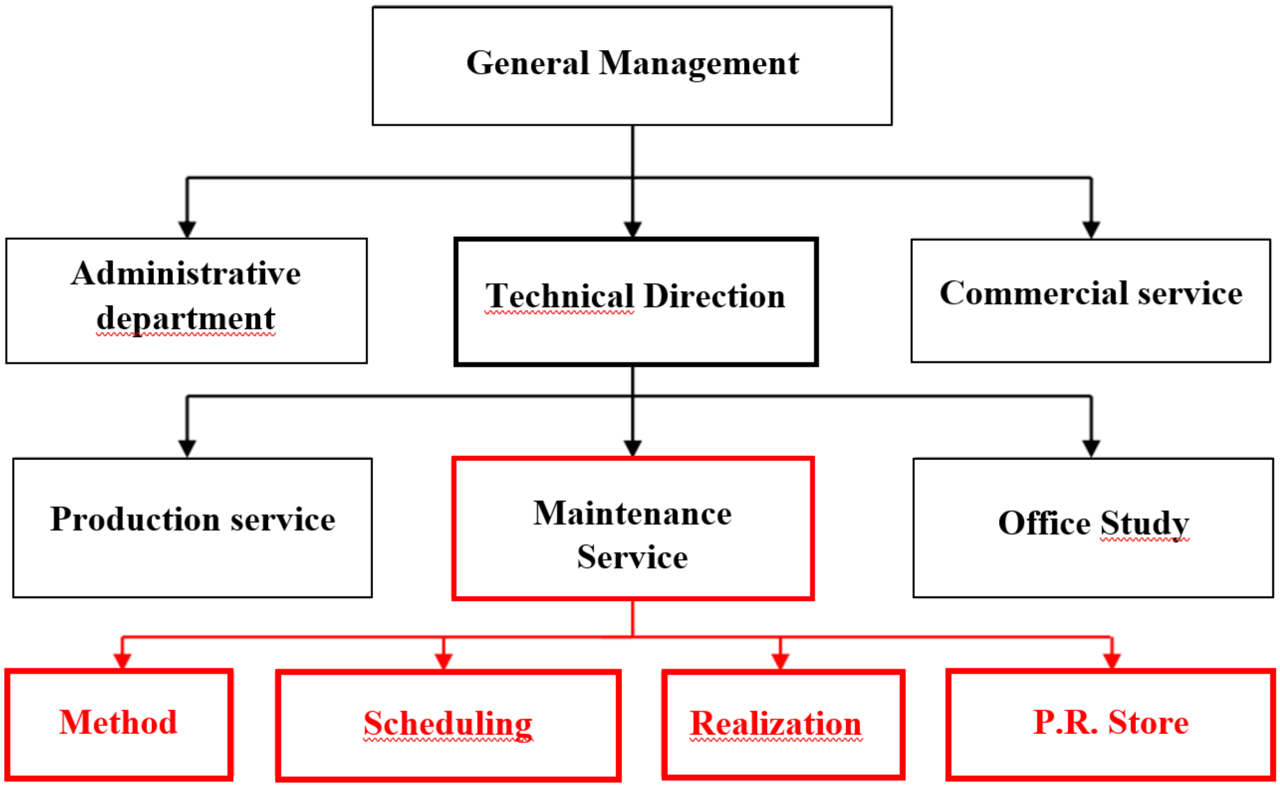


Figure 1: Example of a company structure

3.2. Mission of the maintenance services:

The various tasks of a maintenance services are:

- ✓ Equipment maintenance, of course: corrective and preventive actions, troubleshooting, repairs, and overhauls.
- ✓ Equipment improvement, with a focus on quality, productivity, and safety.
- ✓ New projects: participation in the selection, installation, and commissioning of new equipment.
- ✓ The work relates to hygiene, safety, the environment and pollution, working conditions, and energy management…
- ✓ The execution and repair of spare parts.
- ✓ The procurement and management of tools, spare parts, etc. Various services for production (assembly, for example) or for any other services.
- ✓ General maintenance of administrative or industrial buildings, green spaces, and vehicles.

3.3. Communication within the maintenance department :

We will briefly describe the communication system related to corrective intervention, between the time a failure occurs and the upgrading of the faulty equipment.

Acronyms used: :

WR : Work Request, **WO** : Work Order, **WF** : Work Form (bon de travail **BT**)

SR : Supply Request, **SES** : Store Exit Slip

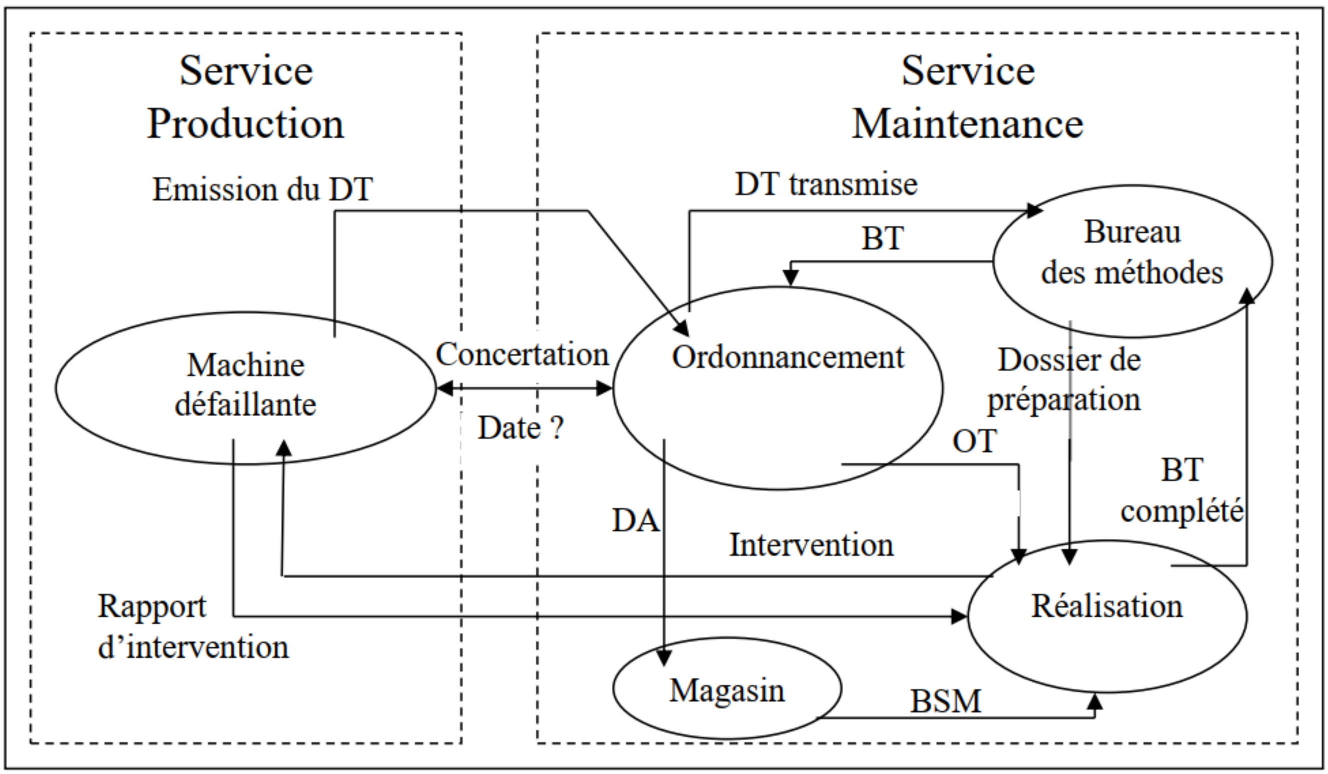


Figure 2: Corrective Action Procedure

This graph shows us the strategic position of the SCHEDULING function for the quality of communication.

- ✓ Indeed, when a machine breaks down, the production department sends a work request to the scheduling department of the maintenance department.
- ✓ L'ordonnancement transmit cette demande au bureau des méthodes.

- ✓ After locating and determining the faulty component(s), the methods department issues a work order for scheduling and forwards the preparation file to the maintenance technician who will carry out the repair.
- ✓ Before leaving for the site, the scheduler must prepare a supply request for the technician. This request will enable them to receive spare parts from the warehouse. Upon receipt, the technician will receive a warehouse release note.
- ✓ After receiving the replacement parts, the technician will begin the repair procedure.
  At the end of the intervention, the technician must start the machine to ensure the effectiveness of the repairs performed.
- ✓ After completing the repairs, the technician must send the intervention report to the methods department to be filed in the history.
- ✓ Finally, production must inform scheduling of the resumption of machine operation.

Note:

The **WR** can be triggered by production (in the case of corrective action in the graph) or by the scheduling itself (in the case of preventive actions).

3.4. The maintenance technician :

a) His training :

The maintenance technician requires versatile training :

- ✓ In terms of equipment technology: mechanical, hydraulic, electronic, computer…etc.
- ✓ In terms of management, he will be responsible, in whole or in part, for managing the entire department, including staff, budget, investments, equipment, necessary supplies, external works, etc.

b) His profession :

Compared to traditional entretien, the role of a maintenance technician has been significantly enhanced by theoretical tools (reliability, maintainability, etc.) and scientific tools (NDT, vibration analysis, etc.). These tools have enriched the tasks related to equipment that is also more sophisticated than before. These tasks are as follows:

- ✓ Maintaining the production facilities.

- ✓ The organization of an after-sales service, participation in studies, with regard to reliability and predicted availability, maintainability, the development of "maintenance plans" for certain contracts, new works.
- ✓ Participation in the implementation of a G.M.A.O, by defining specifications: what data to enter, for what processing, for what use?

In conclusion, we can identify the profile of the maintenance technician as that of a field person, a contact person and a team player, who relies on his initial technical training and then on his experience to constantly improve the handling of the equipment for which he is responsible.

4. Functions and tasks associated with maintenance :

4.1. Study and methods :

The aim is to optimize tasks according to the criteria established within the framework of the company's maintenance policy.

- ❖ **Technical studies :**

Improvement studies, design and pre-design studies of new equipment or works, analysis of working conditions.

- ❖ **Preparation and scheduling :**

Preparation of instruction sheets and ranges for staff, compilation of documentation for interventions, preparation of intervention and spare parts supply schedules, receipt and filing of documents relating to the intervention and updating of technical files.

- ❖ **Economic and financial studies :**

Supply management, cost analysis (maintenance, failure, operation), drafting of specifications and participation in the drafting of contracts (new works, investments, subcontracting), management of the monitoring and acceptance of these contracts.

- ❖ **Maintenance strategy and policies: :**

Definition, selection and development of maintenance procedures (corrective, preventive), control procedures, testing and acceptance procedures, determination of priority preventive action areas, study of intervention triggering procedures, safety management in the organization of the industrial environment.

To fulfill this function, the studies and methods technicians have: technical files providing all the characteristics of the equipment, history sheets summarizing the operations already carried out, documentation from manufacturers and suppliers, computer databases.

4.2. Execution / Implementation :

The multi-technical aspect of this function requires extensive experience with equipment and in-depth knowledge of different technologies. The technician must act with great rigor to make his action effective. It will be helped by the documents and procedures established by the "studies and preparation" function.

The main tasks are: management of maintenance intervention, behavioral knowledge of the equipment, piloting of interventions, application of hygiene instructions and rules, safety and working conditions, installation of machines and equipment (reception, control, commissioning), information of personnel on the equipment, handover of equipment after intervention, management of scheduling, establishment of equipment failure diagnosis, establishment of instructions for use incorporating hygiene and safety instructions, inventory management (spare parts, tools, devices control).

4.3. The documentation and resources function :

Essential to the entire service, this function is the memory of the activity on which subsequent studies will be based in order to define a maintenance policy. It is also an invaluable source of information for the "studies and methods" function.

The main tasks are: development and maintenance of inventories, creation of technical files, histories, economic files, creation of general, technical and regulatory documentation, creation of supplier documentation.

CHAPTER II

MAINTENANCE STRATEGIES

1. The concept of failure :

Definition of failure according to standard NF X 60 – 011: 'alteration or cessation of an asset's ability to perform its required function'.

Usual non-standardized synonyms: "failure" (English), malfunction, damage, damage, anomalies, damage, incidents, defects, breakdowns, deterioration.

A failure can be:

- **Partial**: if there is an alteration in the ability of the property to perform its required function.
- **Complete**: if there is a cessation of the property's ability to perform its required function.
- **Intermittent**: if the property regains its capacity after a limited time without having undergone external corrective action.

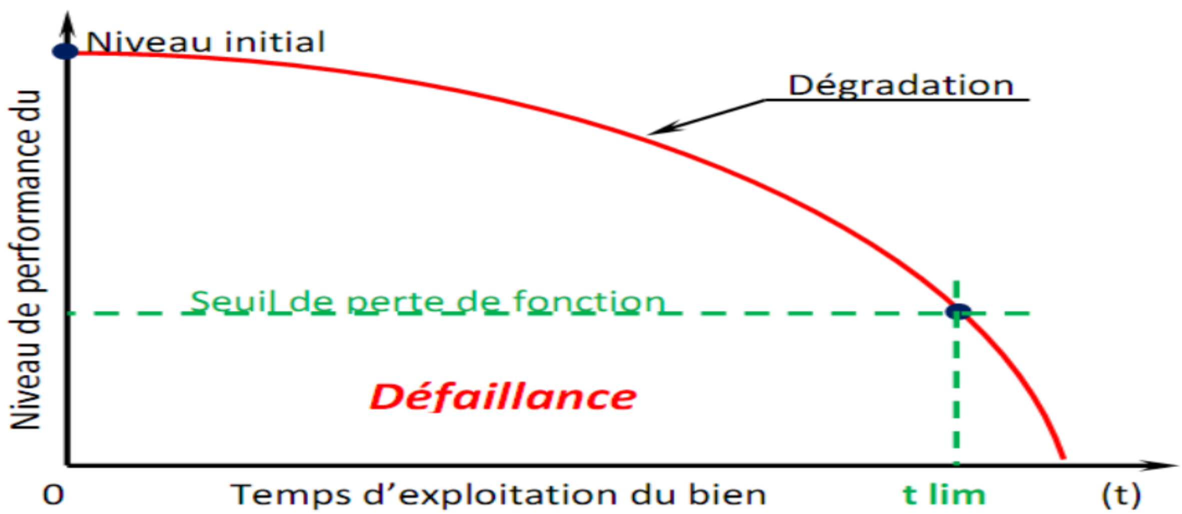


Figure 3: Degradation of the asset and lifespan.

NB: t lim indicates the time of occurrence of the failure.

1.1 Required Function:

A function of a product whose completion is necessary for the provision of a given service. A required function may be a single function or a set of functions. The concept of a service may encompass a mission, that is to say, a succession of phases through which the product must pass over a given period of time.

1.2 Degradation :

A state of an entity exhibiting a loss of performance in one of its functions, or a subset that is itself degraded or even faulty, without functional consequences for the whole. This can also be referred to as drift.

1.3 Triptych "fault-defect-failure" :

Failure is the consequence of a defect, the cause of which is a fault.

Figure 4: Triptych “fault – defect – failure”

- **Fault**: It can be physical (internal or external) or due to the user. This is the notion of 5M(Matières, Matériel, Milieu, Moyens et Main d’œuvre) : Materials, Equipment, Environment, Means and Workforce. It causes an error.
- **Fault:** initially, it is latent, because we do not notice it right away.

  The defect may be :

- Suddenly: if he was unpredictable.
- Catalectic: if it is sudden and irreversible.
- Progressive: if it was predictable and possibly reversible (examples: rusting organ, leak on a valve).
- Early: if it appears at the start of the equipment's life.
- Wear: if it appears at the end of the equipment's life.

1.4 Breakdown :

Condition of a product making it incapable of performing a required function under given conditions of use: this is a condition. It always results from a failure.

2. Maintenance concepts :

The analysis of the different forms of maintenance is based on 4 concepts:

- The events that trigger the action: reference to a schedule, subordination to a type of event (self-diagnosis, information from a sensor, measurement of wear, etc.), the occurrence of a failure.
- The maintenance methods that will be associated with them respectively: systematic preventive maintenance, conditional preventive maintenance, corrective maintenance.
- The actual maintenance operations: inspection, control, troubleshooting, repair, etc.
- Related activities: improvement maintenance, renovation, reconstruction, modernization, new works, security, etc.

This terminological and conceptual reflection represents a basis for reference for:

- The use of a common language for all parties (design, production, service providers, etc.)
- The implementation of computerized maintenance management systems.

3. Maintenance methods :

The choice between maintenance methods is made within the framework of the maintenance policy and must be carried out in agreement with company management. Therefore, to make the right choice, you need to know:

- direction objectives
- The political directions of maintenance.
- The operation and characteristics of the equipment.
- The behavior of the equipment in operation.
- The conditions for applying each method.
- Maintenance costs.
- The costs of lost production.

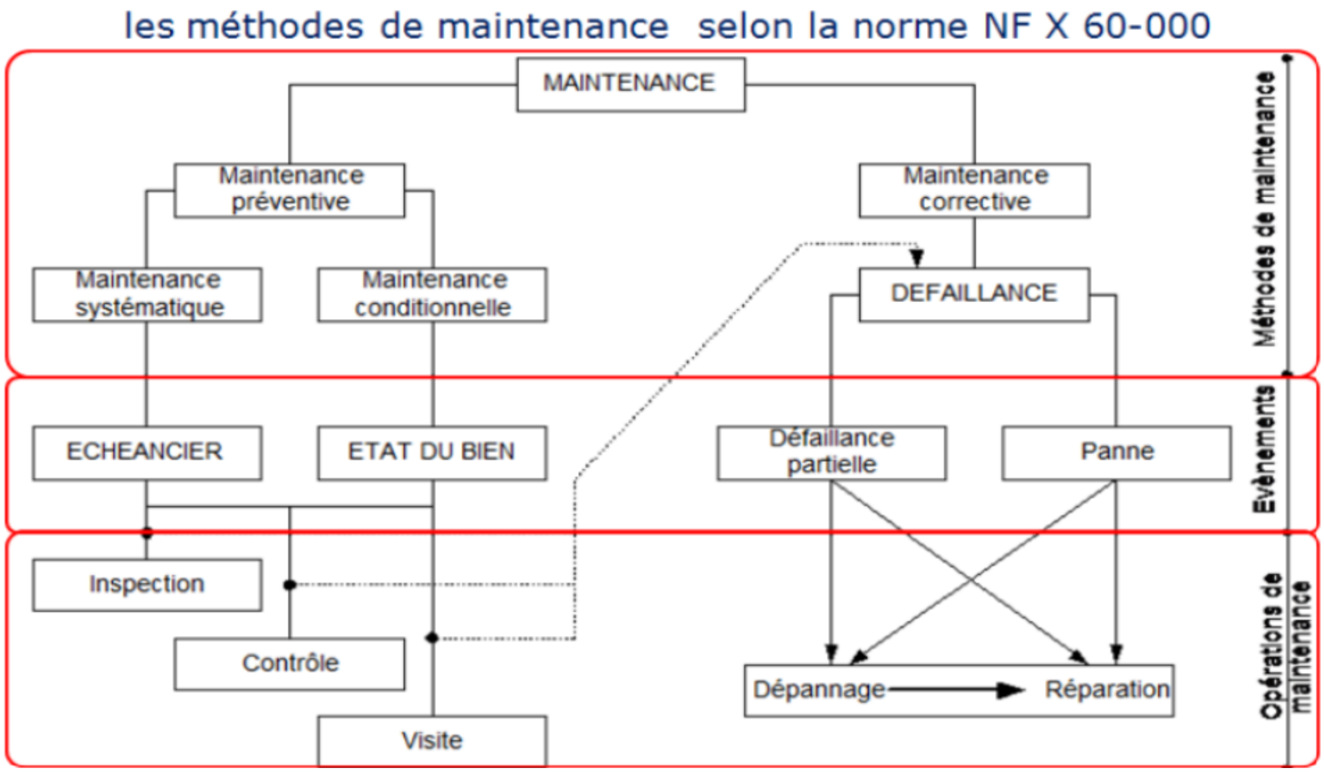


Figure 5 : Maintenance methods

3.1 Corrective maintenance :

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

Corrective maintenance corresponds to a defensive attitude (to endure) while waiting for an unforeseen failure, an attitude characteristic of traditional maintenance.

a- Corrective maintenance operations :

After a failure occurs, the maintenance technician must implement a number of operations, the definitions of which are given below. These operations are carried out in stages (in order):

- **Test**: that is to say, the comparison of measurements with a reference.
- **Detection** or the act of detecting the occurrence of a fault.
- **Localization** or action leading to a precise search for the elements through which the failure manifests itself.
- **Diagnosis**, identification, and analysis of the causes of the failure.
- **Troubleshooting, repair,** or restoration (with or without modification).
- **Verification** of proper operation after intervention.

- **Possible improvement**: that is to say, preventing the recurrence of the fault.
- **History** or recording of the intervention for later use.

b- Time spent on corrective maintenance :

Because corrective maintenance actions are so diverse, it is always difficult to predict the duration of the intervention:

- It can be short (from a few seconds to reset a circuit breaker or change a fuse to a few minutes to change a leaking seal).

- It can be very important (from 0.5 to several hours) in the case of changing several parts simultaneously (engine flooded by a flood).

- It can be major in the event of a death (several days if there is a police investigation).

The maintenance manager must therefore take these distortions into account and have a team available that is responsive to unforeseen events. To reduce intervention times, and therefore direct and indirect costs (equipment downtime costs), one can:

- Implement rational and standardized intervention methods (specific tools, standard exchanges, adapted logistics, etc.).

- Consider the maintainability of equipment from the design stage (accessible inspection hatches, visible wear indicators, etc.).

3.2 Preventive maintenance :

Maintenance carried out according to predetermined criteria, with the intention of reducing the probability of failure of an asset or the degradation of a service provided. It must prevent equipment failures during operation. The cost analysis must highlight a gain compared to the failures it helps to avoid.

Objectives of preventive maintenance :

- Increase equipment lifespan.
- Reduce the likelihood of in-service failures.
- Reduce downtime in case of maintenance or breakdown.
- Prevent and anticipate 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 staff.
- Reduce the maintenance budget.
- Eliminate the causes of serious accidents.

a- Systematic preventive maintenance :

This is preventive maintenance performed according to a schedule based on time or the number of units of use. While time is the most common unit, other units can be used, such as the quantity, length, and mass of the products manufactured, the distance traveled, the number of cycles performed, etc. This intervention frequency is determined from the date of commissioning or after a complete or partial overhaul.

This method requires knowledge of:

i. The behavior of the equipment.
ii. Modes of degradation.
iii. The average time between two failures.

Application case :

- Equipment subject to current legislation (regulatory safety): lifting devices, fire extinguishers, pressure vessels, conveyors, elevators, freight elevators, etc.

- Equipment whose failure could cause serious accidents: all equipment used for public transportation of people, airplanes, trains, etc.

- Equipment with a high cost of failure: elements of an automated production line, processes operating continuously (chemical or metallurgical industries).

- Equipment whose operating costs become abnormally high during their service life: excessive energy consumption, lighting with worn-out lamps, faulty ignition and carburetion (internal combustion engines), etc.

b- Condition-based preventive maintenance :

It is also called predictive maintenance (non-standard term). It is preventive maintenance that is subject to a predetermined type of event (self-diagnosis, information from a sensor, measurement of wear, etc.).

Condition-based maintenance is therefore maintenance dependent on experience and involving information collected in real time. It is characterized by highlighting weaknesses. Depending on the case, it is advisable to put them under surveillance and, from there, to decide on an intervention when a certain threshold is reached. But the checks remain systematic and are part of the non-destructive testing methods. All equipment is concerned; this condition-based preventive maintenance is carried out through relevant measurements on equipment in operation.

The parameters measured may include :

- **i.** The level and quality of the oil.
- **ii.** Temperatures and pressures.
- **iii.** Voltage and current of electrical equipment.
- **iv.** Vibrations and mechanical clearances.
- **v.** The equipment needed to ensure condition-based preventive maintenance must be reliable so as not to lose its purpose. It is often expensive, but in well-chosen cases, it pays for itself quickly.

c- Preventive maintenance operations:

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

- **Inspection** :

Conformity control carried out by measuring, observing, testing or calibrating the significant characteristics of an item; it allows for the detection of anomalies and the execution of simple adjustments that do not require specific tools, nor the stopping of production or equipment (no dismantling).

- **Control** :

Verification of conformity to pre-established data, followed by a judgment. This control may lead to corrective maintenance action or include a decision of refusal, acceptance, or postponement.

- **Visit** :

A detailed and predetermined examination of all (general visit) or part (limited visit) of the various elements of the property, which may involve first and second level maintenance operations; it may also lead to corrective maintenance.

- **Test** :

Comparison of the responses of a system with respect to a reference system or to a significant physical phenomenon of correct operation.

- **Standard exchange**:

Replacement of a defective part or sub-assembly with an identical part, new or previously refurbished, in accordance with the manufacturer's instructions.

- **Revision**:

A comprehensive set of examinations and actions performed to maintain the availability and safety of an asset. An overhaul is often conducted at prescribed intervals or after a specific number of operations. An overhaul requires total or partial dismantling of the item. Therefore, the term "overhaul" should not be confused with "monitoring." A review is a level 4 maintenance action.

The first three operations are also called "**monitoring operations**." They perfectly characterize the learning phase and are absolutely necessary if one wants to understand the evolution of an asset's actual condition. We therefore agree to pay to know and then to prevent problems. They are carried out continuously or at predetermined or unpredictable intervals, calculated based on time or the number of units of use.

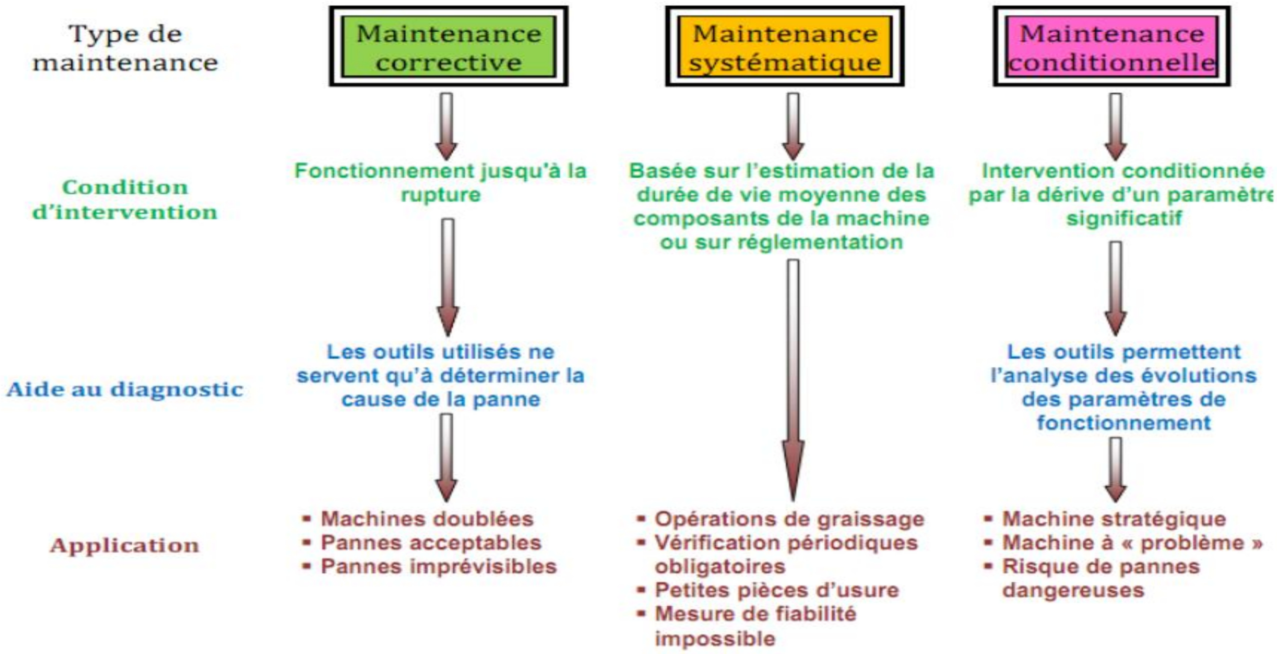


Figure 6: Applications of maintenance methods.

3.3 Improvement maintenance:

The improvement of capital goods 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). This involves modifying the original design to increase component lifespan, standardize components, reduce energy consumption, improve maintainability, and so on. This is a significant advantage if one then decides to build equipment performing the same task but using modern technology: the same problems will no longer be encountered.

a- Objectives of improvement maintenance :

Improvement maintenance is a mindset that requires critical observation skills and a creative attitude. An improvement project necessarily involves a serious economic study: the improvement must be profitable. All equipment is affected, except of course, equipment that is close to being replaced. The objectives of improvement maintenance for an asset are:

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

- The standardization of certain elements or subsets,
- Increased user security.

b- Improvement maintenance operations :

- ✓ **Renovation :**

This involves a complete inspection of all components, full dimensional adjustments or replacement of deformed parts, verification of specifications, and, if necessary, repair of faulty parts and sub-assemblies. This is therefore a possible follow-up to a general review. A renovation may result in a standard exchange.

- ✓ **Reconstruction :**

"Action following the dismantling of the principal asset and replacement of assets nearing the end of their useful life and/or that should be systematically replaced." Reconstruction differs from revision in that it may include modifications and/or improvements. The objective of reconstruction is normally to give an asset a useful life that may be longer than that of the original asset.

Reconstruction requires the replacement of vital parts with original parts or equivalent new parts. Rebuilding may include modernization or modifications. Modifications can bring added value in terms of availability (redundancy), efficiency, safety, etc. However, beware of a particular form of reconstruction: this is "cannibalization," which consists of recovering, from discarded (scrapped) equipment, elements in good condition, of unknown expected lifespan, and using them as spare parts or refurbishment parts. Is this a good solution ?

- ✓ **Modernization :**

It is the replacement of equipment, accessories, and software with sub-assemblies that, thanks to technical improvements not existing on the original item, provide an improvement in the item's suitability for use. Modernization can occur during renovation or reconstruction operations.

3.4 Maintenance levels :

a) 1st level :

Simple adjustments provided by the manufacturer using elements accessible without any dismantling or opening of the equipment, or exchange of consumable elements accessible in complete safety, such as indicator lights or certain fuses, etc….

This type of intervention can be carried out by the operator of the property, on site, without tools and using the operating instructions. The stock of necessary consumable parts is very small.

b) 2nd level :

Troubleshooting by standard exchange of the components provided for this purpose and minor preventive maintenance operations, such as lubrication or functional checks. This type of intervention can be carried out by an authorized technician of average qualification, on site, with the portable tools defined by the maintenance instructions, and using these same instructions.

The necessary transportable spare parts can be obtained immediately and in the immediate vicinity of the operating site.

c) 3rd level :

Identification and diagnosis of faults, repairs by exchange of components or functional elements, minor mechanical repairs and all routine preventive maintenance operations such as general adjustment or realignment of measuring devices.

This type of intervention can be carried out by a specialist technician, on site or in the maintenance room, using the tools provided in the maintenance instructions as well as measuring and adjusting devices, and possibly test and control benches for the equipment and using all the documentation necessary for the maintenance of the asset as well as the parts supplied by the store.

d) 4th level :

All major corrective or preventive maintenance work, with the exception of renovation and reconstruction. This level also includes the adjustment of measuring instruments used for maintenance, and possibly the verification of work standards by specialized bodies.

This type of intervention can be carried out by a team including highly specialized technical supervision, in a specialized workshop.

e) 5th level:

Renovation, reconstruction or execution of major repairs entrusted to a central workshop or an external unit.

By definition, this type of work is therefore carried out by the builder, or by the rebuilder, with means defined by the builder and therefore close to manufacturing.

CHAPTER III

ORGANIZATION AND MANAGEMENT OF MAINTENANCE

1. The concept of reliability :

A. Definition :

Ability of a good to perform a required function under given conditions for a given time (NF EN 13306) or "characteristic of a good expressed by the probability that it performs a required function under given conditions for a given time" (NF X 60–500).

Example: The reliability of a spindle bearing over 20,000 operating hours is equal to 0.9, meaning:

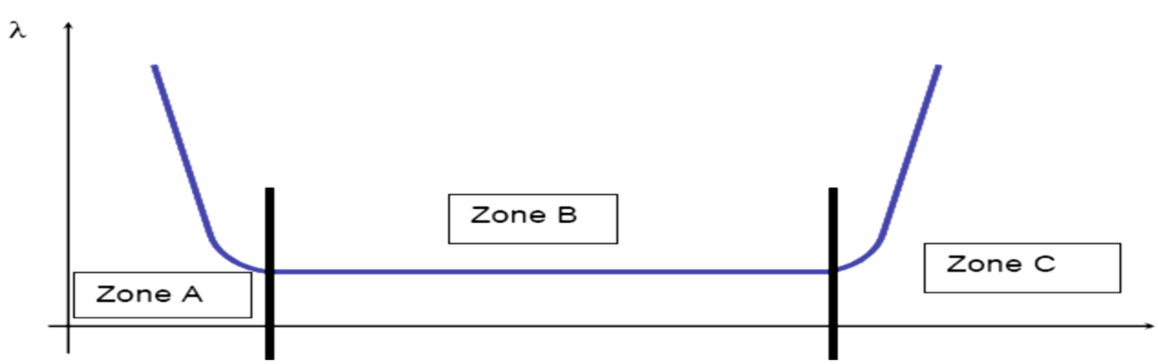
- That there is a 90% chance ➡ **PROBABILITY**
- So that the bearing functions without any signs of wear ➡ **REQUIRED FUNCTION**
- For 20,000 hours ➡ **TIME GIVEN**
- at an average rotational speed of 1500 rpm ➡ **GIVEN CONDITIONS**

Reminder: Probability is a quantity indicating, in the form of a fraction or percentage, the number of times or chances that an event will occur over a total number of trials or attempts.

Note: R is always between 0 and 1.

For example, *a reliability R = 0.92 after 1000 hours means that the product has a 92 out of 100 chance (92% chance) of working correctly during the first 1000 hours.*

The evolution of a piece of equipment's lifespan can be plotted using a curve known as **the bathtub curve**. Depending on whether the equipment is electronic or mechanical, the failure rate patterns differ.



Causes	***Causes***	***Causes***
• Manufacturing defects • Quality control • Design • Assembly • Contamination	• Environment • Random charges • Human error • Natural disasters • Random events	• Fatigue • Corrosion • Age • Friction • Cyclical loads
Remedies	***Remedies***	***Remedies***
• Validation tests • Verification • Quality control	• Redundancy • Improved resistance	• Reduced failure rate • Preventive maintenance • Preventive replacement

Zone A ➡ A time of youth.

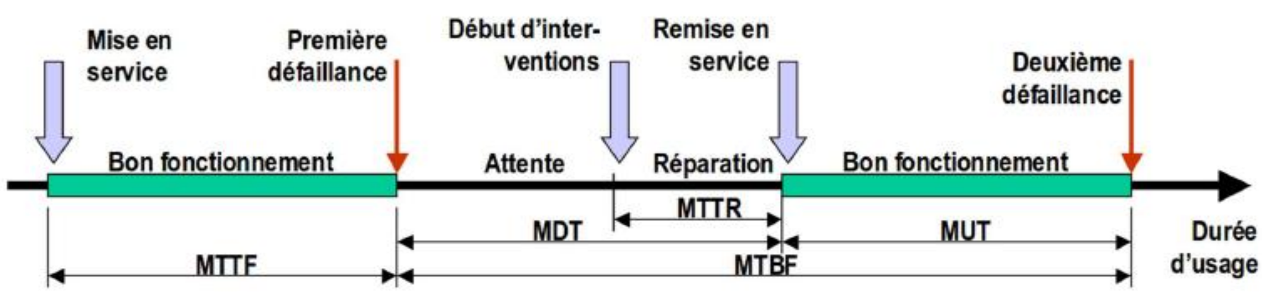
Zone B ➡ Period of maturity, normal operation, random failure independent of time.

Zone C ➡ Old age, wear and tear failures or age-related breakdowns.

The failure rate, denoted λ (t), is an indicator of reliability. It represents a proportion of surviving devices at a given time t.

Indicateurs opérationnels

MTTF	Mean time of first failure	Temps moyen avant première défaillance;
MTBF	Mean time between failure	Temps moyen entre deux défaillances successives;
MDT / MTI	Mean down time	Temps moyen d'indisponibilité ou temps moyen d'arrêt propre
MUT	Mean up time	Temps moyen de disponibilité
MTTR	Mean time to repair	Temps moyen de réparation



B. A special case of the period of maturity :

During this period, the failure rate is essentially constant and equal to the unit of use on the MTBF. The calculations that follow are therefore only valid for this period.

MTBF: Mean Time Between Failures: average of the time between consecutive failures.

MTBF Calculation:

$$\mathrm{MTBF} = \frac{\mathrm{Operating\ Time(OT)}}{\mathrm{Number\ of\ breakdowns}}$$

C. Calculation of the failure rate λ :

$$\lambda = \frac{1}{\mathrm{MTBF}}$$

2. Maintainability :

2.1. Definition :

"Under the given conditions of use for which it was designed, maintainability is the ability of an item to be maintained or restored to a state in which it can perform a required function, when maintenance is carried out under given conditions, with prescribed procedures and means." (NF EN 13306).

2.2. Maintainability calculation :

Maintainability can be characterized by its MTTR.

MTTR : (Mean Time To Repair) or Average Technical Repair Time.

$$\textbf{MTTR} = \frac{\sum Response\ time\ for\ (n)\ breakdowns}{Number\ of\ breakdowns\ (n)}$$

2.3. Repair rate μ :

$$\mu = \frac{1}{\mathrm{MTTR}}$$

3. The concept of availability :

3.1. Definition :

The ability of an asset to be in a state to perform a required function under given conditions, at a given moment or during a given interval of time, assuming that the supply of the necessary external means is ensured.

This capability depends on a combination of reliability, maintainability, and maintenance logistics. External resources required other than maintenance logistics do not affect the availability of the asset (NF EN 13306).

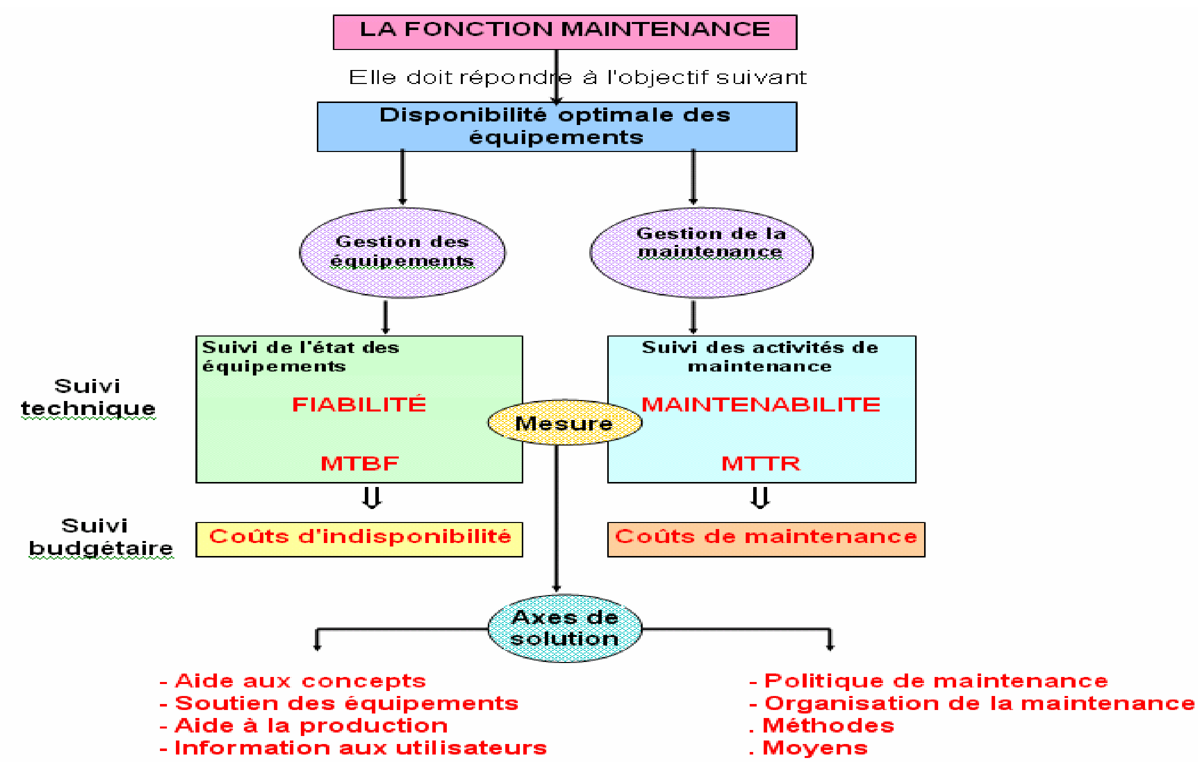
3.2. Quantification of availability :

The average availability over a given time interval can be evaluated using the ratio:

$$D = \frac{MTBF}{MTBF + MTTR}$$

Note: By setting availability, you set the MTTR and MTBF.

Failure tables are very useful for performing calculations.



3.3. Failure Mode, Effects, and Criticality Analysis (FMECA) :

FMECA is a preventive analysis method that identifies and highlights potential risks [2]. "Design FMECA" makes it possible to determine weaknesses, to specify ways to protect against certain failures and to classify failures according to certain criteria (frequency, detection capability, criticality, severity, etc.).

The purpose of the FMECA method is to:

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

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

3.4. Qualitative analysis of the failure :

The first step is to identify, as comprehensively as possible, all potential and plausible failure modes of the entity being analyzed. At this stage, it is assumed that the failure can occur but does not necessarily happen.

To determine the cause of failure, an effective research technique is to use the "fishbone" diagram. Using a diagram for each failure mode, interdependent causes are identified and grouped in a tree-like fashion.

Each mode causes a failure effect, that is, a consequence on the function or on surrounding systems. Some manufacturers define the effect as "what the customer might notice assuming the failure occurs".

The ability to detect failure can be anticipated and facilitated by a number of devices. The aim is to identify existing means, either to prevent the occurrence of the cause, or to detect the failure.

3.5. Quantitative failure analysis criteria :

The aim is to be able to assess the failure using several criteria by assigning a score to each criterion. Generally, three criteria or indices are used: **Frequency - Severity - Detection**.

- The frequency index "F" or occurrence index "O" indicates the probability that the cause will occur and lead to the failure mode in question. It is also an estimate of the probability of occurrence of the failure cause under consideration.
- The severity index "S" focuses on the severity caused by the effect. It also represents the impact of the failure's effects on the product or an estimate of the severity of the maximum effect of the failure.
- The detection index "D", more often called risk of non-detection for the sake of brevity, marks the probability that, given the cause and mode, the failure will reach the user.
- The criticality index "This is the result of the risk factors presented above. It is determined by the product of the three indices. $C = D.O.S$

If each index is rated from 1 to 4, the criticality can range from 1 to 64. The higher the index, the greater the risk associated with potential failures. A product improvement strategy involves addressing criticality levels exceeding a given threshold.

Table 1. Failure Mode, Effect and Criticality Analysis.

Severity S: impact of failures on the product or production tool			
1	**No damage:** minor failure not causing production stoppage and no significant degradation of equipment.	3	**Important:** failure causing a significant shutdown, and requiring major intervention.
2	**Average:** failure causing a production stoppage and requiring minor intervention.	4	**Catastrophic:** failure causing a shutdown involving serious problems.
Frequency of occurrence O: probability of occurrence of a cause or failure			
1	**Exceptional:** the possibility of failure is practically non-existent.	3	**Some:** there have traditionally been failures in the past.
2	**Rare:** an occasional failure has already occurred or could occur.	4	**Very common:** it is almost certain that the failure will occur often.
Non-detection D: probability of not perceiving the existence of a cause or failure			
1	**Warning signs:** the operator can easily detect the failure	3	**No sign:** finding the fault is not easy.
2	**Few signs:** the failure can be detected with some investigation.	4	**Expertise required:** the fault is not detectable or its location requires in-depth expertise.

Table 2. Criticality scale C = D.O.S

C < 16	Disregard
16≤ C <32	Low-frequency preventive maintenance
32≤ C <36	High-frequency preventive maintenance
36≤ C <48	Search for improvement
48≤ C <64	Resume the design

4. Application of FMECA(AMDEC) :

These tools can provide a very useful framework because the qualitative and quantitative analyses of FMECA are part of a global methodology (also applicable to a product already designed):

- Definition of the study ;
- Study preparation ;
- Analysis and evaluation of potential failures ;
- Corrective or preventive actions;
- Reassessment after corrective actions ;
- Residual criticality and list of critical points ;

Example: Reliability / Failure Rate

In one company, end-of-production testing and customer feedback allowed for the creation of a historical record of the number of equipment failures per operating time interval. This operating time interval is equal to one month and the study covers seven months during which 72 pieces of equipment were found to be out of order. The table below summarizes the elements of this history.

Intervalle	1	2	3	4	5	6	7
Intervalle de temps de fonctionnement avant une défaillance (en mois).	0 à 1	1 à 2	2 à 3	3 à 4	4 à 5	5 à 6	6 à 7
Nombre de matériels défaillants dans l'intervalle.	25	10	7	6	5	9	10

1/ Reliability calculation R(t):

1.1/ Calculate the reliability over the first 3 months in %, that is to say the probability of non-failure over the first 3 months.

R (3 month) = (72 – 42) / 72 = 0,42 R = 42%

Number of failures = 25 + 10 + 7 = 42

Conclusion

There is a 42% chance that the equipment will function without failure during the first three months of use.

1.2/ Complete the following table :

Intervalle	1	2	3	4	5	6	7
Nombre de matériels sans défaillance à la fin de l'intervalle	47	37	30	24	19	10	0
FIABILITE R (t)	0,65	0,51	0,42	0,33	0,26	0,14	0

2/ Calculation of the Failure Rate λ(t) :

2.1/ Complete the table below:

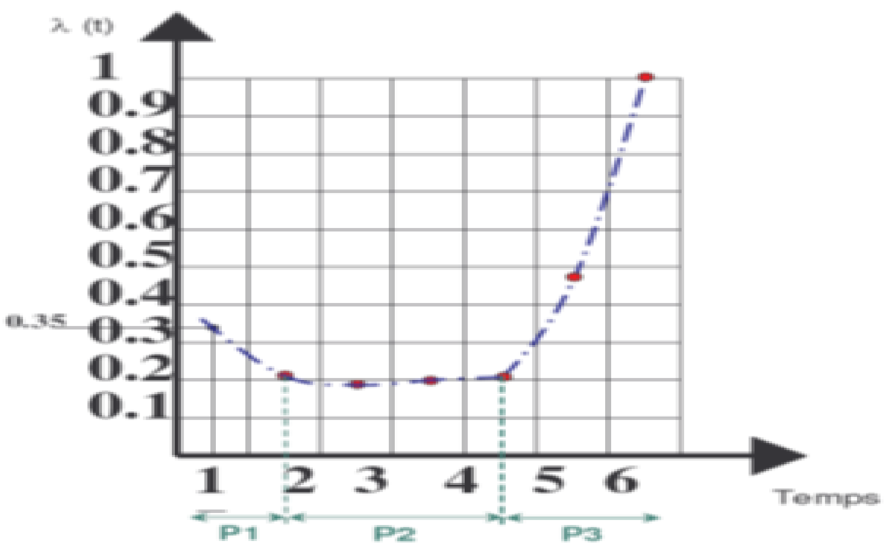
Reminder : λ (t) = A / B

A : Number of equipment failures during a time interval Δt.

B: Number of equipment in service at the start of Δt .

Intervalle	1	2	3	4	5	6	7
A	25	10	7	6	5	9	10
B	72	47	37	30	24	19	10
λ (t)	0,34	0,21	0,19	0,2	0,21	0,47	1

2.2/ Graphically represent the curve of variation of the failure rate as a function of time.



Period 1:

Early failure period (or youth period) is the initial possible period in the life of an entity, starting at a given moment and during which the failure rate rapidly decreases to a minimum or plateau.

Period 2:

The constant rate failure period (or constant rate of failure period) is the possible period in the life of an entity during which the instantaneous rate of failure is practically constant.

Period 3:

The aging failure period (or end-of-life period) is the final possible period in the life of an entity during which the instantaneous failure rate grows rapidly from a minimum or plateau.

CHAPTER IV

TROUBLESHOOTING OF VARIOUS PARTS OF ELECTRICAL MACHINES

1. Rules and Methods in Industrial Electrical Maintenance and Troubleshooting:

Maintenance and troubleshooting in industrial electricity are subject to specific regulations and best practices.

Rule 1: Compliance with Standards NF C 18-510 and NF C 15-100:

These standards define the safety and compliance requirements for industrial electrical installations.

Method 1: Failure Analysis: :

During troubleshooting, it is essential to analyze the causes of the failure to prevent it from recurring. This may include:

1. Identifying the symptoms
2. Root cause analysis
3. Implementation of corrective actions

Rule 2: Staff Training

Only qualified personnel trained in industrial electrical maintenance techniques are authorized to work on the installations.

Best Practices :

1. Use appropriate personal protective equipment (gloves, helmet, etc.)
2. Implement a preventive maintenance plan for critical equipment
3. Maintain an up-to-date record of interventions and failures

Conclusion:

Maintenance and troubleshooting in industrial electricity require specific technical skills and adherence to strict safety standards.

2. Industrial Electrical Maintenance and Troubleshooting :

Maintenance and troubleshooting of industrial electrical systems are essential to ensuring the reliability and safety of industrial operations. This section explores common maintenance and troubleshooting methods and practices.

3. Industrial Electrical Maintenance :

Industrial electrical maintenance aims to ensure the proper functioning and safety of electrical equipment. This section introduces the objectives and types of maintenance used in industrial environments.

3.1. Maintenance Methods :

Maintenance methods include preventive maintenance, corrective maintenance, and predictive maintenance. This section describes each method, its advantages, and its application in industrial electrical systems.

3.2. Electrical Systems Troubleshooting :

Troubleshooting involves identifying and repairing faults in industrial electrical systems. This section provides common troubleshooting techniques, including diagnostic procedures and the necessary tools.

3.3. Tools and Equipment :

Tools and equipment used for maintenance and troubleshooting include multimeters, oscilloscopes, and test devices. This section examines commonly used tools and their applications in industrial environments:

- Electrical troubleshooting requires in-depth knowledge of the systems.
- The right tools are essential for effective troubleshooting.
- Wiring diagrams help visualize circuits for troubleshooting.
- Use a multimeter to test circuits during troubleshooting.
- Systematic troubleshooting methods are the most effective.

- Consult the electrical diagrams before starting troubleshooting.
- Frequent failures should be documented for future analysis.
- The tests may include voltage and resistivity checks.
- Sometimes, simply replacing a faulty part is enough.
- Professionals must always work according to safety standards.
- Failure reports help with the traceability of problems.
- Collaboration with other technicians can be beneficial.
- A good diagnosis beforehand can speed up the repair process.
- Understanding how systems work is crucial for troubleshooting.
- Risk assessment must be carried out before working on any equipment.
- Modern diagnostic tools are often indispensable.
- Use quality replacement parts to avoid further breakdowns.
- Documenting procedures can aid in learning.
- Notes on best troubleshooting practices should be followed.
- The systems must be regularly tested and maintained.
- Taking preventative measures helps reduce the need for troubleshooting.

Example 1: Troubleshooting an Electric Motor.

An industrial electric motor has stopped starting. Perform a diagnostic to identify the cause of the failure and propose a troubleshooting solution.

Solution: Here are the diagnostic steps:

1. Check the motor's power supply (voltage, current, connections)
2. Check the condition of the motor windings (resistance, insulation)
3. Examine the mechanical components (bearings, ventilation)
4. Replace the faulty components (capacitor, contactor, etc.)

Once the fault has been identified and repaired, perform functional tests to ensure the engine is working properly.

Example 2 : Preventive Maintenance Planning

Develop a preventive maintenance plan for an industrial piece of equipment of your choice (for example, an air compressor).

Solution: Here are the main steps:

1. **Visual inspection:** Check the overall condition of the equipment (leaks, vibrations, etc.)
2. **Mechanical maintenance:** Lubricate moving parts, replace filters, etc.
3. **Electrical maintenance:** Check connections, protections, operating parameters, etc.
4. **Performance tests:** Measure the main operating parameters (flow rate, pressure, etc.)
5. **Planning of interventions:** Define a preventive maintenance schedule.

4. Definitions of terms related to industrial electrical maintenance and troubleshooting :

Electrical troubleshooting requires a good understanding of complex systems, especially in an industrial context.

4.1. Electrical troubleshooting :

Electrical troubleshooting is the process of identifying and correcting faults in an electrical system. This often involves thorough testing and diagnostics.

4.2. Diagnostic tool :

Diagnostic tools, such as multimeters and oscilloscopes, help to determine the cause of faults in an electrical circuit.

4.3. Wiring diagram :

A wiring diagram is a map of the electrical connections of a piece of equipment, essential for troubleshooting and maintenance.

5. Breakdown :

A breakdown is the failure of a system or device, resulting in the cessation of its operation. Identifying the source of the breakdown is crucial for any repair.

6. Troubleshooting procedure :

A troubleshooting procedure is a series of systematic steps followed to identify and resolve electrical problems.

7. Spare part :

A spare part is a component that can be used to replace a defective part in an electrical device, allowing its operation to be restored.

8. Compliance tests :

Compliance tests assess whether a system or device meets current safety standards, ensuring its proper functioning.

9. Corrective maintenance :

Corrective maintenance is the type of maintenance performed after a failure to restore a system to working order. It differs from preventive maintenance.

10. Incident report :

An incident report documents the details of a failure, the actions taken to resolve it, and the lessons learned to improve future interventions.

11. Risk assessment :

A risk assessment involves analyzing the potential hazards associated with electrical work in order to minimize accidents.

Understanding these terms is crucial for professionals working in electrical maintenance and troubleshooting, especially in industries.

CHAPTER V

GENERAL INFORMATION ON COMPUTER-AIDED MAINTENANCE (CAM)

1. Definition :

GMAO stands for Computer-Aided Maintenance Management. It is specialized software for managing a technical service. Computer-Aided Maintenance Management consists of a database (history) which is populated by maintenance personnel via a form. Each CMMS is customized according to the specific needs of historical data management or the operation of a site.

Caractéristiques générales :

A CMMS software allows you to build a database in which you will find:

- The store's items,
- Les fournisseurs,
- Managing the entry and exit of items,
- Purchasing management,
- Asset management (equipment and sub-assemblies),
- The management of corrective interventions,
- The management of preventive interventions,
- Managing requests for intervention,
- Financial analysis and monitoring of maintenance indicators,
- Customer contact management and invoicing.

2. Computer tools :

2.1. General Concept of Computer-Aided Maintenance :

Given the sheer volume of information that needs to be handled during maintenance activities, the presence of computer tools for entering, storing, and processing this information is essential. Numerous software programs are available on the market, which can be classified into five categories:

1. The CMMS « Industrial » :

Computerized Maintenance Management System (**CMMS**): management of technical ratios, warehousing, machine records, project tracking, planning…

2. The CMMS « tertiary » :

Building management, geographic information, asset management, planning (BMS, HMS),

Building Management System (BMS) , Heritage Management System (HMS)

3. Algorithmic diagnostic assistance :

Fault trees, maintainability calculations, reliability calculations…

4. Monitoring :

Signal and alarm analysis,

5. Artificial intelligence-assisted diagnostics :

Problem-solving methods analogous to human reasoning (expert systems, neural networks, etc.)

2.2. The functions of a CMMS (1):

CMMS (Computerized Maintenance Management System) systems are most often applications developed using a DBMS (Database Management System), allowing for the scheduling and monitoring of all maintenance activities, objects, and personnel involved, from technical, budgetary, and organizational perspectives. A CMMS must therefore perform the following functions:

- **Maintenance activity management** :

Managing the various interventions based on the documents.

- **Management of retained items** :

Location, technical specifications, maintenance characteristics, drift measurements, results of rounds and visits, failure history, consumption, interventions carried out…

- **Inventory and supply management** :

Component sheets and nomenclatures, supplier sheets, automatic replenishment, voluntary orders, entry of movements.

2.3. The functions of a CMMS (2) :

- **Economic management** :

Indirect hourly costs (penalties), direct hourly costs, overhead hourly costs, work orders, invoices, breakdown of these costs by maintained item, by maintenance policy, by function, sector...

- **Investment Management** :

Purchase and installation costs, estimated durability, types of financing…information that allows us to estimate the average operating cost and the technical depreciation of the equipment.

- **Human resources management** :

Workforce structure (qualifications, specializations, seniority, etc.), record of training hours, working conditions (number of accidents, occupational illnesses, absences, etc.), record of salaries and promotions...

3. Managing a CMMS project :

The steps involved in implementing a CMMS can be summarized as follows:

3.1. Drafting the specifications (especially defining the need) :

- Volume of hardware inventory to be maintained and equipment documentation to be computerized;
- Degree of sophistication of the software (the more powerful it is, the more complex it is to use);
- Statistics: calculations to be performed, desired level of diagnosis, exporting the file to Excel for example, etc.
- People who are expected to use it: geographical location, level of computer skills, department to which they are attached;
- Define the editions you wish to produce;

- Level of complexity of the industrial environment: simple or multi-site, one or more stores, etc.
- Desired networking (SQL, SAP, etc.)
- Define the budget to be allocated (hardware and software, training, maintenance).
- Define the time allocated for implementation (installation, training, external support);
- Define the preventive measures to be followed (maintenance plan);
- Define the store follow-up to be carried out;
- Define the documents (and their contents) useful for the execution of the maintenance process (Notices, DT, AT, etc.) including safety (fire permits, CO2 lockouts, etc.);
- Identify the tools in place (existing CMMS, paper or Excel entry of interventions), and determine whether they should be used;
- Define the IT monitoring for the proper operation of the software (implementation, hardware and software maintenance);
- Define the means of backup and archiving;

3.2. Software selection :

- Specific development or purchase of software;
- Orientation towards 1 software or a set of software (CMMS, lubrication, stock management) with the necessary interfaces;
- Choose an IT service provider if the company does not have internal IT expertise;

3.3. Implementation :

a). Hardware and software installation

b). Tests

3.4. Staff training :

- ✓ General computer training (e.g., Windows operating system);
- ✓ Software-specific training;
- ✓ Each person receives a lesson;
- ✓ Ensure that people use their new knowledge very quickly after training, provide a period of support;

3.5. Use / Operation of the CMMS;

Beforehand:

- Entry of the complete inventory of equipment;

Use of CMMS:

- Entry of Requests for Intervention and Work Orders;
- Entry of intervention reports and closure;
- Recording of alarms for preventive interventions;
- Other seizures;
- Creation / editing of statistics (indicators, Pareto, etc.);
- Archiving/backups;

4. Conditions for the success of a CMMS project

The most important recommendations are as follows:

- Clearly state your objectives:

What is a CMMS (Computerized Maintenance Management System) for? Who is it for? What are the expected results?

- Express the need in terms of strictly useful functions and eliminate unnecessary functions.
- Working in a multidisciplinary group to formally conduct a needs analysis and to write a functional specification document that is subject to consensus among all potential users.
- Do not underestimate the preliminary steps that need to be taken before any final decision.
- An error or omission made during the drafting phase of the specifications is practically irrecoverable once the product has been purchased.

This results in additional delays and costs for making corrections or defining new features in the software.

- Ask shortlisted suppliers to provide customer references where their CMMS applications are in use. Don't hesitate to visit sites where these software programs are implemented to get feedback from the users.
- Verify the sustainability of the products and the supplier's ability to evolve over time
- Verify the sellers' ability to provide maintenance and support.
- Plan for a training period for all staff (from workers to the highest technical manager of the company).

❖ Verify the suitability of the organization to the software and avoid the opposite situation.

Indeed, the cultural shift required by CMMS necessitates sustained efforts and must be a long-term strategic priority for the company. This is also true for the implementation of new maintenance policies such as Total Productive Maintenance (TPM) and Reliability-Based Maintenance (RBM).

❖ It is preferable to choose a project manager who is independent of the production and maintenance departments and who can ensure the sustainability of the CMMS application and will be the "champion" of the CMMS or the leader to use the Anglo-Saxon terminology.

5. Functions of a CMMS software :

5.1. Corporate asset management:

OptiMaint adapts to and tracks all types of assets (industrial or commercial). Asset management must be both simple and powerful so that users can easily enter and find the information they need.

Asset management allows you to:

- Structure all the characteristics of the resources to be maintained in a database.
- Define all levels of amputation and technical and financial analysis.

To adapt to needs, **OptiMaint** allows you to define mandatory input fields and remove from the display fields that are not of interest to the company. To adapt perfectly, the user can create their own input fields. The dashboard (the equipment sheet) is very rich in information. Maximum asset availability depends on the organization and planning of interventions. **OptiMaint** allows you to optimize all interventions related to preventive, corrective, conditional, etc. maintenance.

5.2. Corrective maintenance :

Corrective maintenance can be carried out either on the basis of a request for intervention, a work order or simply without any prior request (Figure 6).

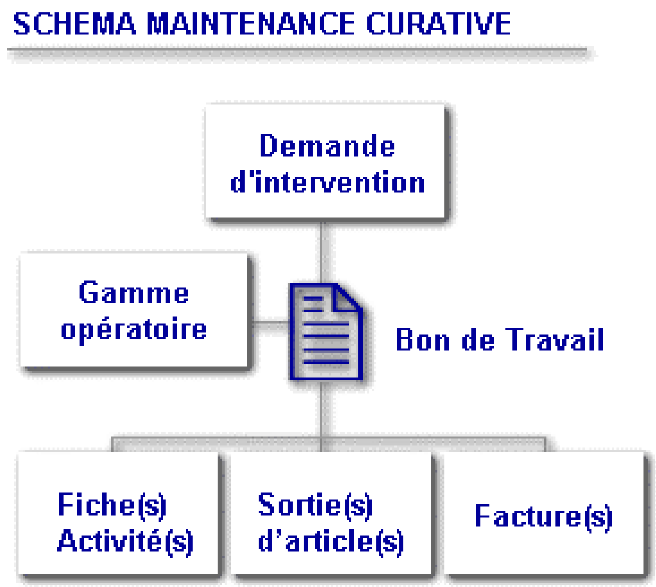


Figure 6: Management of corrective maintenance by a CMMS.

5.3. Preventive maintenance:

OptiMaint automatically generates work orders for all interventions that need to be carried out regularly based, for example, on a calendar schedule or according to time counters (Figure 7).

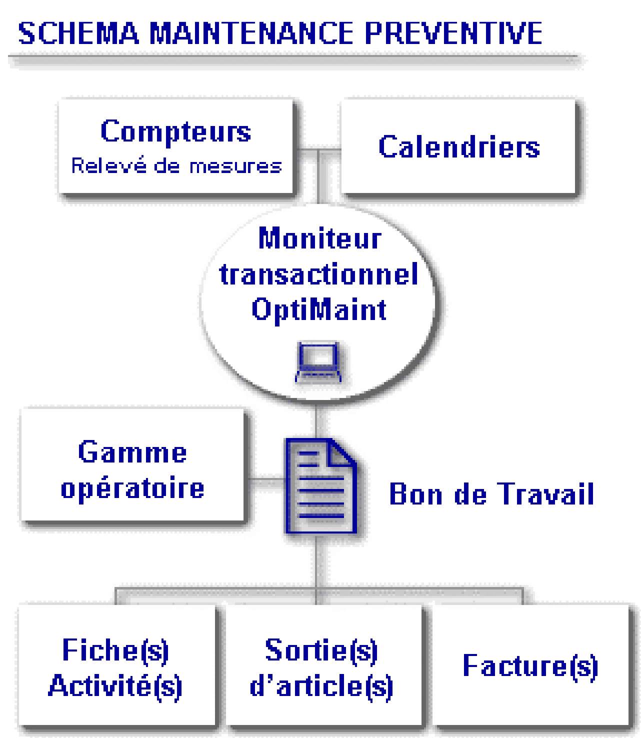


Figure 7: Gestion de la maintenance préventive par une GMAO

5.4. Condition-Based Maintenance:

Based on measurements and predefined conditions, OptiMaint automatically generates work orders.

5.5. Purchasing management:

OptiMaint allows you to manage all types of purchases (Figure 8). OptiMaint enables you to follow up on late deliveries by mail, fax, or email. Upon receipt, a quantity/quality check with dispute management is possible for supplier quotation purposes. The invoice generated from the order or the delivery note(s) may require a validation phase.

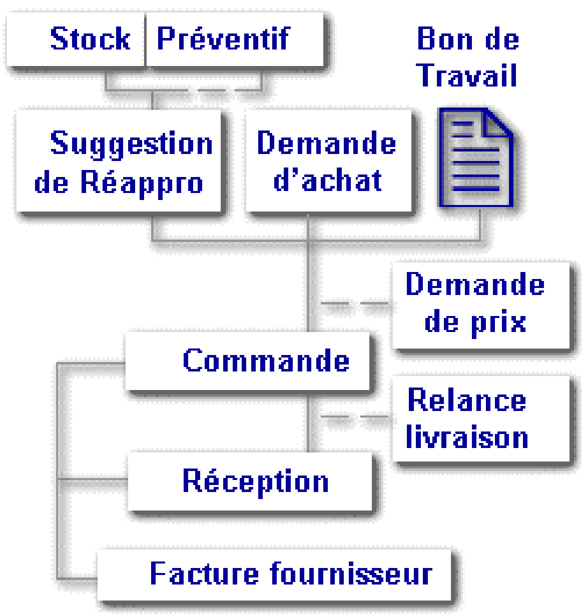


Figure 8: Management of corrective purchases using a CMMS

5.6. Inventory management:

OptiMaint supports the overall management of all stocks with the ability to populate (Figure 9). OptiMaint also allows document management on all product sheets, equipment, suppliers etc.

It is possible to have an automatic exchange of data with different purchasing, stock, ERP software... which avoids double entries, always a source of error and wasted time!

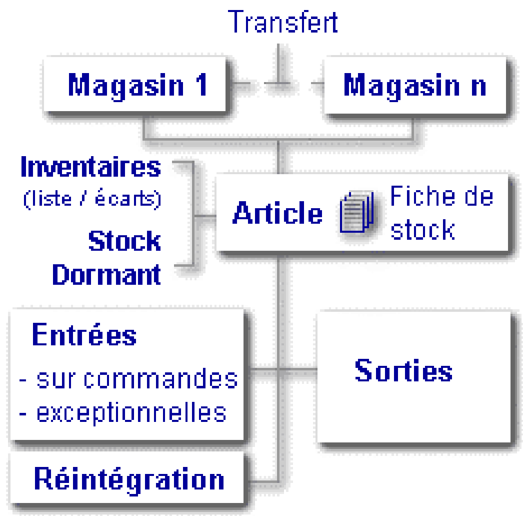


Figure 9: Inventory management using a CMMS.

5.7. Budget management:

OptiMaint allows you to define annual budgets (with the possibility of detailing by month) for (Figure 10): OptiMaint automatically manages the allocation of costs in relation to a budget.

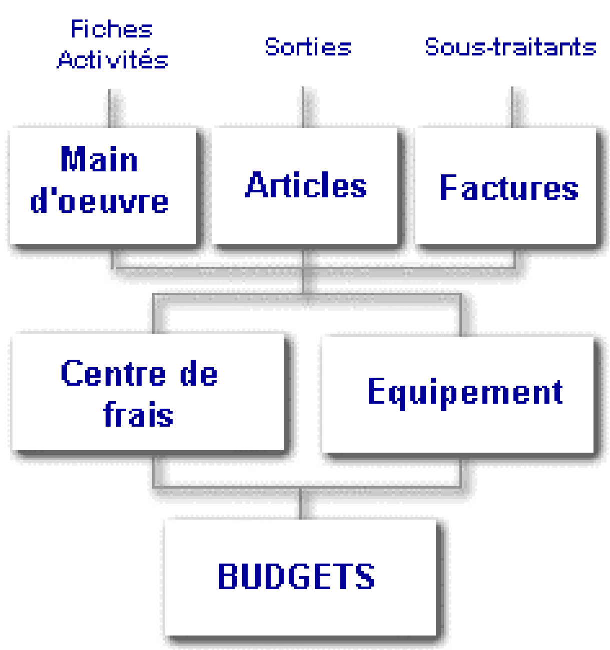


Figure 10: Budget management using a CMMS.

5.8. Investment Project Management :

OptiMaint manages new investment projects (new works) outside the operating budget (improvement projects, design projects, etc.). Any new project can be assigned to a division (sector, etc.) or a cost center (workshop, cost center, etc.) possibly under a specific heading (Figure 11).

It is possible to define budgets for labor, items and subcontractors or simply an overall budget. OptiMaint's terminology is customizable. It is possible to replace the word "Cost Center" with "Workshop". This way, all screens and print reports will be personalized!

It is possible to have automatic data exchange with purchasing, inventory, and ER software, which avoids double entries, always a source of errors and wasted time!

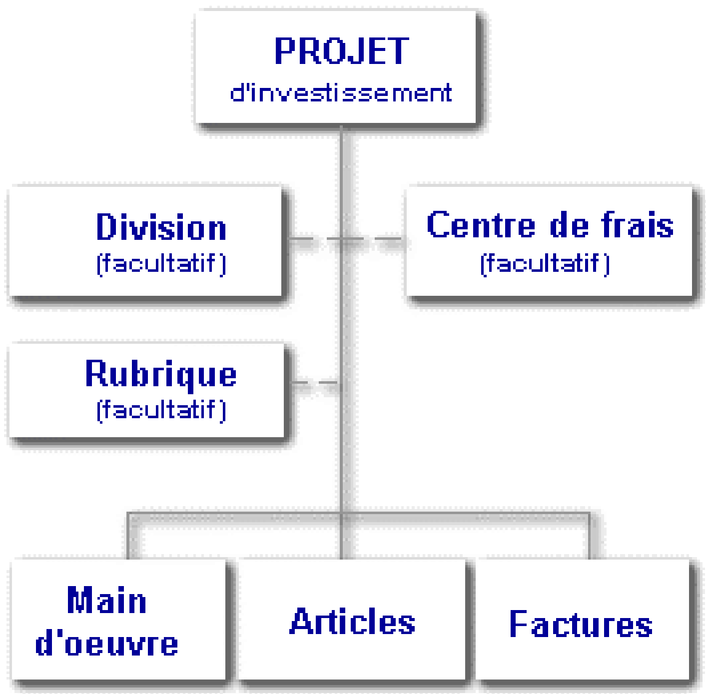


Figure 11: Investment project management using a CMMS.

Références Bibliographiques

- K. Bourouni ; Cours de Maintenance Industrielle, Version 1.0, Ecole national d’ingénieur de Tunis, Septembre 2004.
- S. Tafraoui ; Maintenance Industrielle, Université de Béchar, 2024.
- T. Frédéric ; Cours de Maintenance, HEI Hautes Études d'Ingénieur.