1 MAINTENANCE ANALYSIS ELEMENTS

I.1 INTRODUCTION

Maintenance is a complex function which, depending on the type of process, can be decisive for the success of a company. The functions that make it up and the actions that carry them out must be carefully balanced so that the overall performance of the production tool is optimized [1]. The whole difficulty lies in this adjustment which must be adjusted taking into account numerous elements: at the company level: the economic and social context; at the installation level: interaction with other systems (in particular that of production); at the level of the maintenance system: the various effects of each activity (studies, preparation, scheduling, etc.) [1].

To be effective, you must first have as clear an idea as possible of the mechanisms that influence significant quantities (number of breakdowns, repair times, logistical times, preventive maintenance costs, material storage costs, communication actions). , etc.). It is then necessary to measure these quantities and construct indicators to judge the state of the maintenance system and to identify areas for improvement. Finally, we must find the appropriate actions and try to evaluate their impact.

We have tried to give a general idea of the maintenance system by breaking it down into sub-functions and indicating their interactions. Pre-diagnoses covering the different activities can be proposed to evaluate the performance of an installation's maintenance system. They are possibly supplemented by more in-depth diagnostics in order to quantify important indicators with greater precision. This presentation of maintenance was intended to be functional so as to remain generic and “neutral” [2]. The organization which will then be applied to the maintenance system reflects strategic choices.

Indeed, depending on which one is established, certain functions will be reinforced while others will be more or less neglected. For example, we could favor short-term or, on the contrary, long-term actions, a field vision or a method approach... With the structure that it decides to put in place, management therefore has a means of action essential to support its policy.

I.2 ROLE OF MAINTENANCE

The place of maintenance is increasingly important in the activity and productivity of companies. Today, maintenance activities no longer only aim to repair equipment (corrective maintenance) but also to anticipate breakdowns and malfunctions (preventive maintenance). Thanks to new technologies, notably electronic sensors and new CMMS solutions, it is even possible to predict breakdowns and carry out interventions before they occur (forecast or predictive maintenance). In short, the role of maintenance is to implement the famous proverb “prevention is better than cure” [3]. The objective of maintenance is therefore to keep production tools operational safely while reducing production costs. To meet growing economic challenges, it is a source of optimization and even profits.

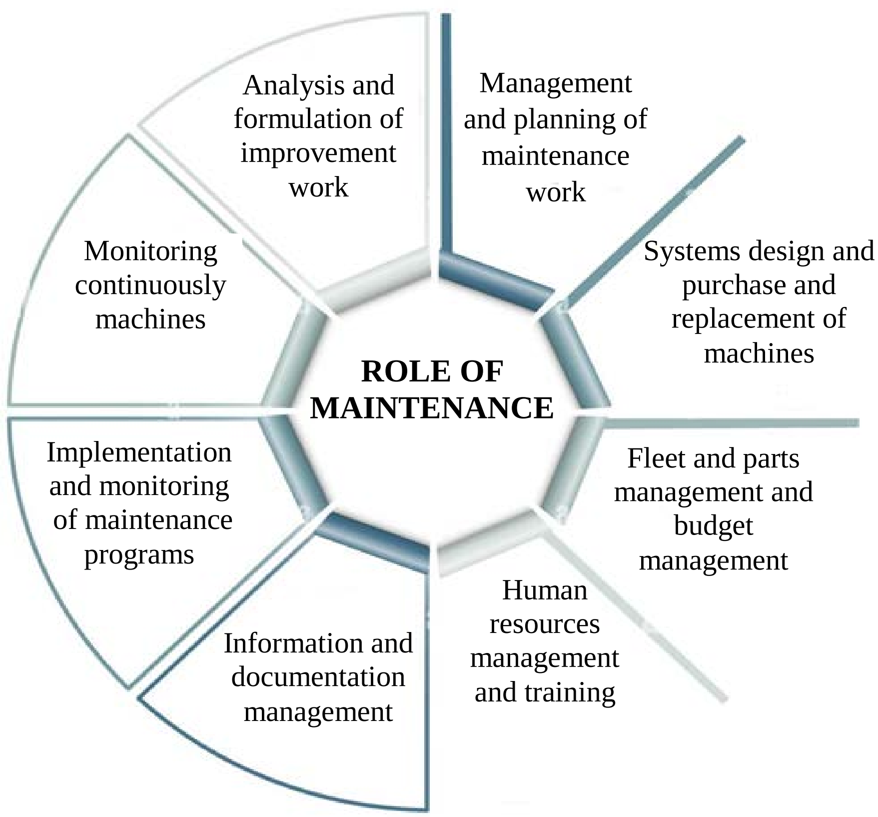

Figure I.1 Role of maintenance

The role of a maintenance department is therefore broader today than before, and managers and technicians are involved in structural projects which must integrate numerous parameters such as cost and deadlines, quality, safety or environment [3].

It makes it possible to avoid production losses and, consequently, to eliminate all shortfalls.” Its primary goal is to maintain the production potential, that is to say the permanent availability and optimum efficiency of the installations. A complex function if ever there was one, maintenance is subdivided into mainly management-oriented maintenance of operations and mainly technical maintenance of works. The first is usually taken care of by those responsible for the maintenance department [4].

The maintenance department must implement the maintenance policy defined by the company's management; this policy should make it possible to achieve the maximum efficiency of production systems. The maintenance function will then be required to establish targeted forecasts:

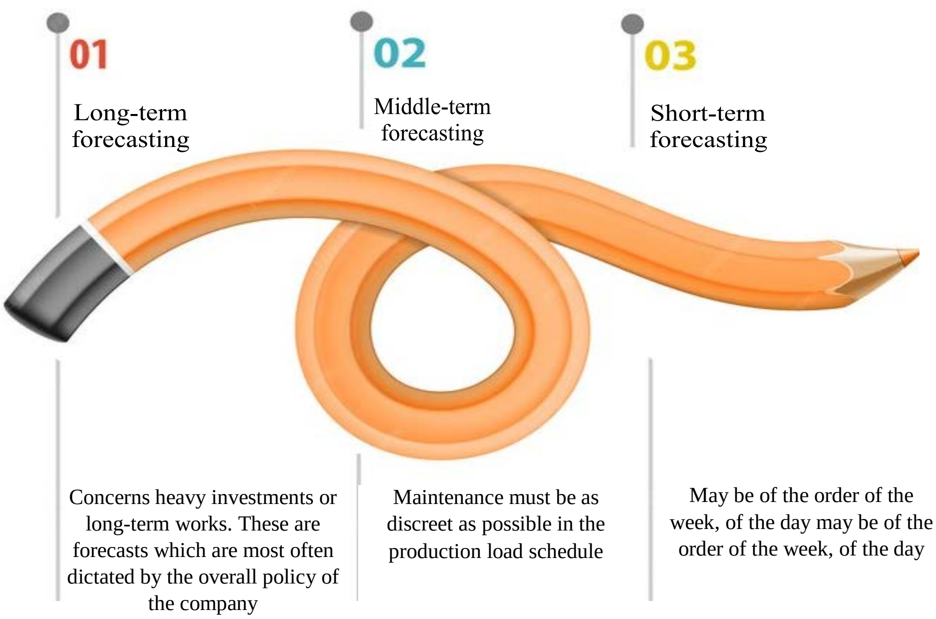

Figure I.2 Industrial maintenance service

I.3 MANAGEMENT AND EVOLUTION OF MAINTENANCE

In the company, the function "maintenance" consists less and less often of repairing the work tool but more and more frequently of anticipating its malfunctions. The shutdown or abnormal operation of the production tool, and the failure to meet the resulting deadlines, in fact generate costs that companies are no longer able to bear. They can no longer wait for the breakdown to occur to remedy it but must now organize themselves to carry out the various operations that make it possible to avoid it. We thus went from a "corrective maintenance" has "preventive maintenance", which results in the definition of action plans and interventions on the equipment, the replacement of certain parts in the process of deterioration, the regular lubrication or cleaning of certain assemblies in order to limit wear. [1].

These preventive actions were initially carried out systematically according to predefined schedules. They effectively made it possible to anticipate breakdowns, but at the cost of a significant increase in maintenance costs. Thanks to the evolution of diagnostic and control technologies, in particular sensors, new maintenance is developing today. It uses fault prediction techniques such as, for example, vibration or oil analysis. This final stage of maintenance, called “predictive” or “conditional preventive”, allows parts to be replaced before they break.

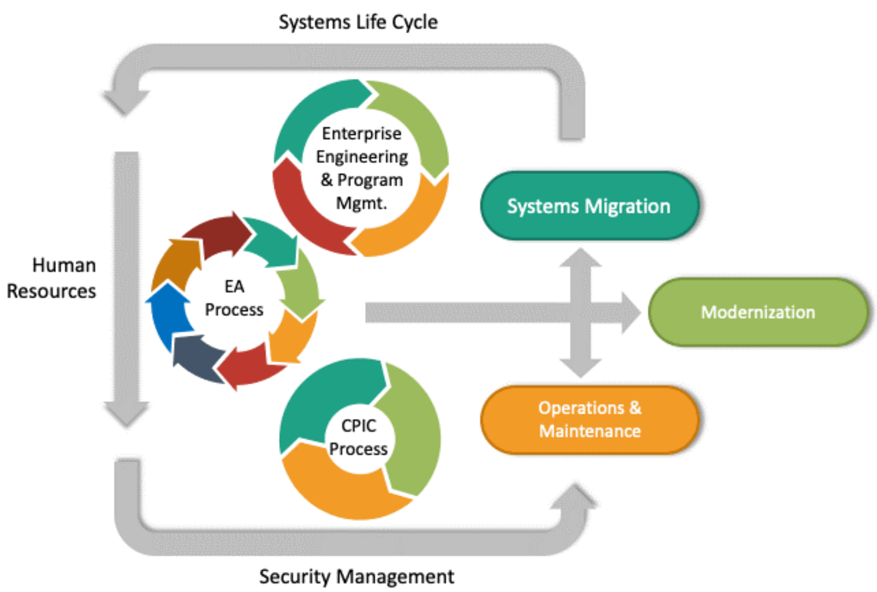

Figure I.3 Position of maintenance in the life cycle of a system

The transition from curative maintenance to conditional preventive maintenance is however not systematic. It aims less to minimize maintenance costs than to optimize them according to production objectives. It may therefore be economically profitable to apply systematic preventive maintenance to a particular production process.

For example, applying preventive maintenance for a flagship product with a high profit margin, while curative maintenance may prove to be the only "economically acceptable". From meme for another product or equipment, on which we have the experience and the habit of repairing breakdowns applying corrective maintenance [5].

Companies therefore make choices among the different types of maintenance based on multiple technical, economic elements, internal or external factors: the frequency of cyclical or random equipment failures, the skills and competencies of maintenance personnel or subcontractors, policies and methods of work organization, competitive position on the market, products, etc.

The development of preventive maintenance tends to favor a second evolution: the simplest maintenance activities (first or even second level according to AFNOR standards) are transferred to production operators, which should lead to a reduction in the number of agents of maintenance. This development is, however, not systematic. Various factors can sometimes work against this:

first of all, technical factors, such as the coexistence in the equipment of several generations of machines and therefore different technologies, the physical distance of the operator from his production tool, his inability to access this tool for security reasons…; organizational factors as well, in the case where the intervention of a decentralized maintenance service proves more efficient or faster; finally, human factors, when for example production operators are not sufficiently trained or motivated, or even not authorized, to carry out certain maintenance activities.

Third major development: the share of maintenance activities entrusted to specialized external companies is increasing. Several factors explain this development of subcontracting. Carried out by specialists, it is on a technical level a guarantee of quality and efficiency. From an organizational point of view, companies are currently tending to refocus on their main function, and to delegate what does not relate to their business [3].

Finally, outsourcing minimizes maintenance costs: the company pays for the service and therefore does not have to bear the cost linked to the permanent presence of a very important maintenance service. But maintenance outsourcing will not necessarily continue to develop. Until now, it has invested in peripheral production segments at the heart of the companies' business. However, it cannot go beyond this stage without risking seriously weakening them. Due to the constant evolution of technologies, companies would then lose areas of skills and knowledge.

They would then lack perspective and visibility to assess the value of the maintenance interventions carried out and would become incapable of judging the quality of the interventions, and especially the relevance of the costs invoiced. Last major development partly linked to the development of subcontracting: the generalization of standards and methods. The requirements of the ordering companies translate into the need for service providers to hold different certifications (an ISO standard, for example), and different authorizations. More generally, companies are committed to total quality policies, and maintenance activities must apply these policies. However, certification sometimes appears restrictive. The problem is not so much posed by the standards themselves as by the methodologies which are deduced from them, which are very demanding in particular regarding the formalization of intervention procedures.

I.4 TYPES OF MAINTENANCE

There are two main types of maintenance: corrective maintenance and preventive maintenance. Corrective maintenance includes palliative maintenance or disaster maintenance. For its part, preventive maintenance is subdivided into systematic, conditional and predictive maintenance. The figure presents the organization of these different types of maintenance [6].

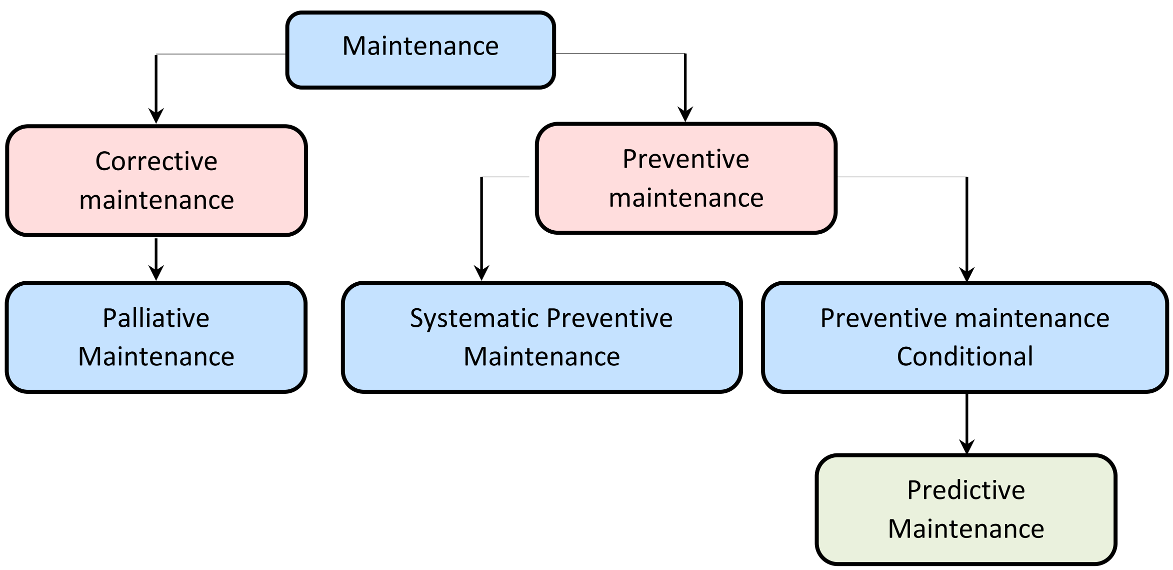

Figure I.3 The different types of maintenance

Corrective maintenance as well as systematic preventive maintenance are the traditional forms of maintenance. The first still constitutes a fundamental activity today while the second is increasingly replaced by conditional preventive maintenance which, like predictive maintenance, reflects new trends in maintenance [3]. Both rely on advances in computing and implement sophisticated diagnostic techniques.

I.4.1 Corrective maintenance:

Corrective maintenance (or curative maintenance or even disaster maintenance) follows a machine failure. It includes two types of intervention: troubleshooting and correction of the causes of the failure. Troubleshooting is the first step in corrective maintenance. Sometimes called palliative maintenance, it is equivalent to emergency maintenance, a temporary and immediate activity following a malfunction or any other malfunction. Furthermore, the correction phase makes it possible to identify and correct the source of the failure to avoid repetitive incidents [5].

Although this is not one of the objectives of corrective maintenance, this type of unplanned intervention still allows the reduction of the frequency of breakdowns as well as maintenance costs by improving reliability. of the machine: elimination or reduction of breakdowns and anomalies, increase in the lifespan of parts, reduction of consumption (for example lubricants), standardization of components, etc.

The cost of corrective maintenance is extremely high since it occurs following an unforeseen event and it is often impossible to determine in advance how much production downtime it will require. It therefore involves delays and losses in production, the immobilization of employees, the accumulation of overtime for the maintenance team (repair) and for the production team (recovery of lost time).

I.4.2 Preventive maintenance

This aims to slow down the degradation of the equipment and therefore reduce the probability of a failure occurring. There is also so-called round maintenance which is characterized by regular monitoring of the equipment in the form of high-frequency visits, leading to minor maintenance work if necessary.

So-called Mixed Maintenance consists of taking advantage of the opportunity offered by the shutdown of a system to carry out other interventions in parallel, planned or not, on other elements. It should be noted that the system considered can be:

- A machine: when equipment fails, we take advantage of the shutdown
- From the machine to carry out interventions on other equipment
- From the same machine;

I.4.2.1 Systematic preventive maintenance: Unlike corrective maintenance undertaken following a breakdown or malfunction, systematic preventive maintenance is subject to a program and a fixed schedule with the aim of reducing the probability of failure or degradation of a machine Manufacturing.

This is proactive rather than reactive maintenance, maintenance “thought out ahead of operation”. Consequently, the teams responsible for the design, study and improvement of the equipment must take into account the objectives of preventive maintenance by integrating, for example, different instruments and electronic systems for detection, monitoring, measurement and regulation from the design stage.

Preventative maintenance programs are usually developed by maintenance managers (i.e., line maintenance). They cover cleaning, lubrication, re-tightening, periodic inspections and examinations of machines (in whole or in part), adjustments, preventive replacement of minor parts or components, and any other work whose frequency has been programmed at advance.

This type of maintenance is very expensive since it involves, among other things, the replacement of parts whose life cycle has not been completed, production stoppages and frequent checks. Furthermore, systematic preventive maintenance does not provide any real guarantees regarding the reliability of the machines. On the other hand, monitoring in working condition sometimes proves less damaging than occasional stops which allow the degree of wear to be examined [7].

Systematic maintenance was therefore quickly discarded except in cases where safety was at stake, for example in the chemical and petroleum industries. Companies increasingly prefer condition-based maintenance. However, it must be remembered that these two types of maintenance are complementary, certain work such as cleaning, lubrication, tightening, etc.

I.4.2.2 Conditional preventive maintenance

“An example allows us to clearly understand what distinguishes these two types of intervention. When we do an oil change every 10,000 or 15,000 km, it is systematic preventive maintenance; on the other hand, if we wait until the oil has lost its essential qualities before replacing it, this is conditional preventive maintenance”

Rather than following a fixed schedule, condition-based preventive maintenance relies on non-destructive diagnostic techniques that provide information on the state of degradation of a machine. It is used to optimize maintenance by “triggering revisions at the last moment and limiting systematic work, and therefore costs. »

The control techniques most often implemented as part of a condition-based preventive maintenance program are vibration analysis and oil analysis [6].

The first detects the phenomena of unbalance, misalignment, poor mechanical tightening, gear damage, poor condition of a transmission belt, electrical vibrations, scaling of bearings and friction. At second allows certain operating anomalies linked to the phenomenon of oil degradation and pollution to be detected. For example, the presence of lubricant in the friction zones will indicate wear of the installation while the evolution of the number, nature, size and morphology of the particles suspended in the oil will provide the information on its degree of degradation [7].

There are many other techniques for monitoring industrial machinery, some making it possible to control surface conditions and the degree of wear deterioration of a part (photography, endoscopy, holography, stroboscopy, molding and impression, vibration control, etc. .), to detect cracks or welding defects (bleeding, radiography, gammagraphy, ultrasound, eddy current, magnetoscopy, ultrasound emission, modal analysis, holographic interferometry, etc.) or even to note the dissipation of energy and the heating state of the equipment (infrared thermography and thermometry, etc.).

Table 1: Main characteristic of the four types of maintenance

Type of maintenance	Trigger
Corrective maintenance	Carried out after a failure when the damage or failure is neither progressive nor gradual
Systematic preventive maintenance	Carried out according to a schedule when the appearance of a damage could have an impact on safety or before the appearance of a failure which is not progressive or gradual
Conditional preventive maintenance	Carried out depending on the condition of the machine, before the failure appears or when the damage is progressive and gradual. Information provided by a sensor, wear measurement, etc.
Preventive maintenance	Carried out following the evolution of a symptom or deterioration (for example, the critical threshold of a vibration level) before the appearance of the failure

Usually, using just one of these techniques is not enough; They must, depending on the type of machine, be combined to facilitate the development of a diagnosis. Electronics and IT have been determining factors in the development of condition-based preventive maintenance.

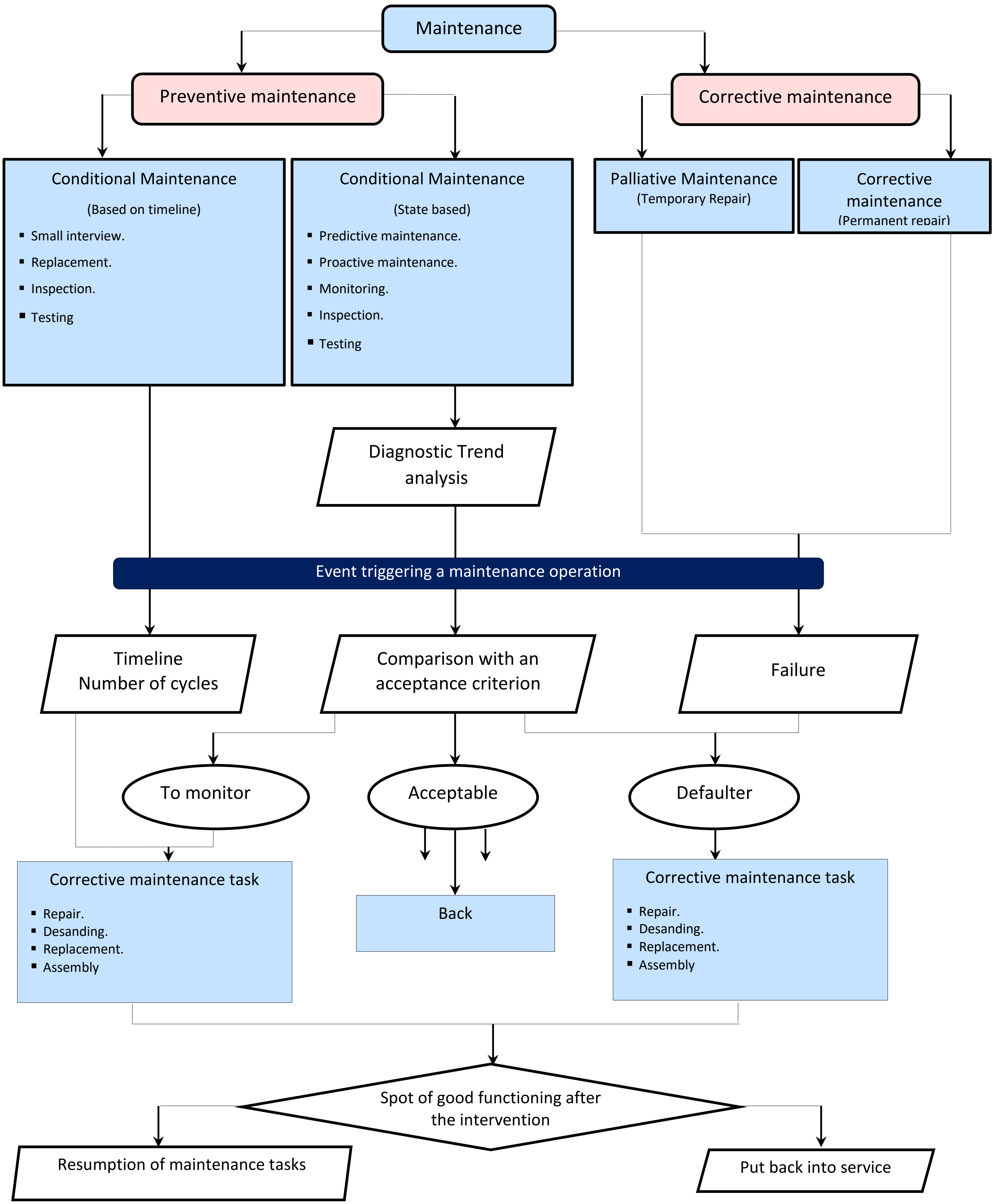

Figure I.4 Diagram of different maintenance policies [3]

The development of software packages specialized in maintenance techniques has enabled companies to check, on an ad hoc basis, the condition of equipment, to carry out to analyze failures, evaluate the degree of reliability of machines and monitor the evolution or life cycle of manufacturing facilities. However, it seems that the use of IT in this area is still reserved for large companies and industrial maintenance, particularly in refineries and paper mills. The following table summarizes the main characteristics of these different forms of maintenance.

In addition, if conditional preventive maintenance allows a significant reduction in costs related to corrective or palliative maintenance, it also entails a high investment in monitoring and analysis instrumentation and training costs for the maintenance personnel who are involved in it. responsible. This type of maintenance is therefore more often carried out by a specialized external service or by suppliers who have the laboratories and equipment necessary for these analyzes and control processes.

I.4.2.3 Predictive maintenance

Predictive maintenance is closely linked to condition-based preventive maintenance. It covers the same types of work. However, unlike condition-based maintenance which uses a sensor or measurement of wear, predictive maintenance is based on the evolution of a symptom or deterioration. For example, we will try to evaluate, depending on the level of vibrations, the moment when the critical threshold will be reached. The work will then be scheduled over time, neither too early nor too late, so as to avoid reaching this critical threshold.

Figure I.5 Predictive maintenance diagram

According to R. Keith Mobley [5], a predictive maintenance program can reduce maintenance costs, the number of breakdowns, parts inventory, service downtime and overtime. It also increases the useful life of machines, productivity and profits.

I.5 MAINTENANCE POLICY

Defining the maintenance policy for equipment consists of voluntarily deciding:

- What preventive maintenance is profitable to do?
- What are the economically profitable ways to minimize maintenance failure costs of curative maintenance:

The general overview of the different stages for choosing the technical and economic maintenance policy for equipment is presented in eleven stages.

1. Identify the conditions of use of the equipment
2. Define legal maintenance operations
3. Develop lubrication plans
4. Define preventive maintenance operations
5. Define spare parts to stock
6. Define curative maintenance aids
7. Structuring implementation documents

8. Estimate the cost of the maintenance policy choice made
9. Demonstrate the profitability of the maintenance policy choice made
10. Sell the maintenance policy choice made
11. Measure the results obtained and update the choice if necessary

I.6 MAINTENANCE OPTIMIZATION LEVELS AND ANALYSIS

AFNOR has subdivided maintenance activities according to the nature of the work, the locations of intervention, the personnel involved (user, qualified technician, specialized technician, very specialized team, supplier or external service), the necessary tools, documentation and necessary parts. The five demarcated levels are as follows:

Levels	Trigger
1st Level	Simple adjustments provided by the manufacturer using accessible components without any dismantling or opening of the equipment or exchange of consumable elements accessible in complete safety, such as indicator lights or certain fuses. This type of intervention can be carried out by the operator of the property on site without tools and with the help of the instructions for use. Part stock or operational control.
2nd Level	Troubleshooting by standard exchange of the elements provided for this purpose and minor preventive maintenance operations. Such as lubrication or proper functioning control. This type of intervention can be carried out by an authorized average quantification technician on site with portable tools defined by the maintenance instructions and with the help of these same instructions. The necessary transportable spare parts can be obtained without delay and in the immediate vicinity of the operating site.
3rd Level	Identification and diagnosis of breakdowns, 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 specialized technician on site or in the maintenance room using the tools provided in the maintenance instructions as well as measuring and adjustment devices and possibly test benches. and control of equipment and using all the documentation necessary for the maintenance of the property as well as the parts supplied by the store
4th Level	All major corrective or preventive maintenance work with the exception of renovation and reconstruction. This level also includes the adjustment of measuring devices used for maintenance and possibly the verification of working standards by specialized organizations. This type of intervention can be carried out by a team including very specialized technical support in a specialized workshop equipped with general tools (mechanical means of wiring all general or specific documentation)
5th Level	Renovation, reconstruction or execution of major repartitions entrusted to a central workshop or to an external unit. By definition, this type of work is therefore carried out by the manufacturer or by the rebuilder with means defined by the manufacturer and therefore close to manufacturing.

To keep up with technological development and the increasing efficiency constraints of our societies, maintenance approaches and associated concepts have had to evolve. Numerous synthesis works [4] present the different policies and their applicability in an operational context. We can classify these approaches into three levels with on one side two levels associated with the very typologies of these policies, corrective or preventive, and on the other side the organization of maintenance with a more systemic vision of it. This classification is shown in Figure I.5.

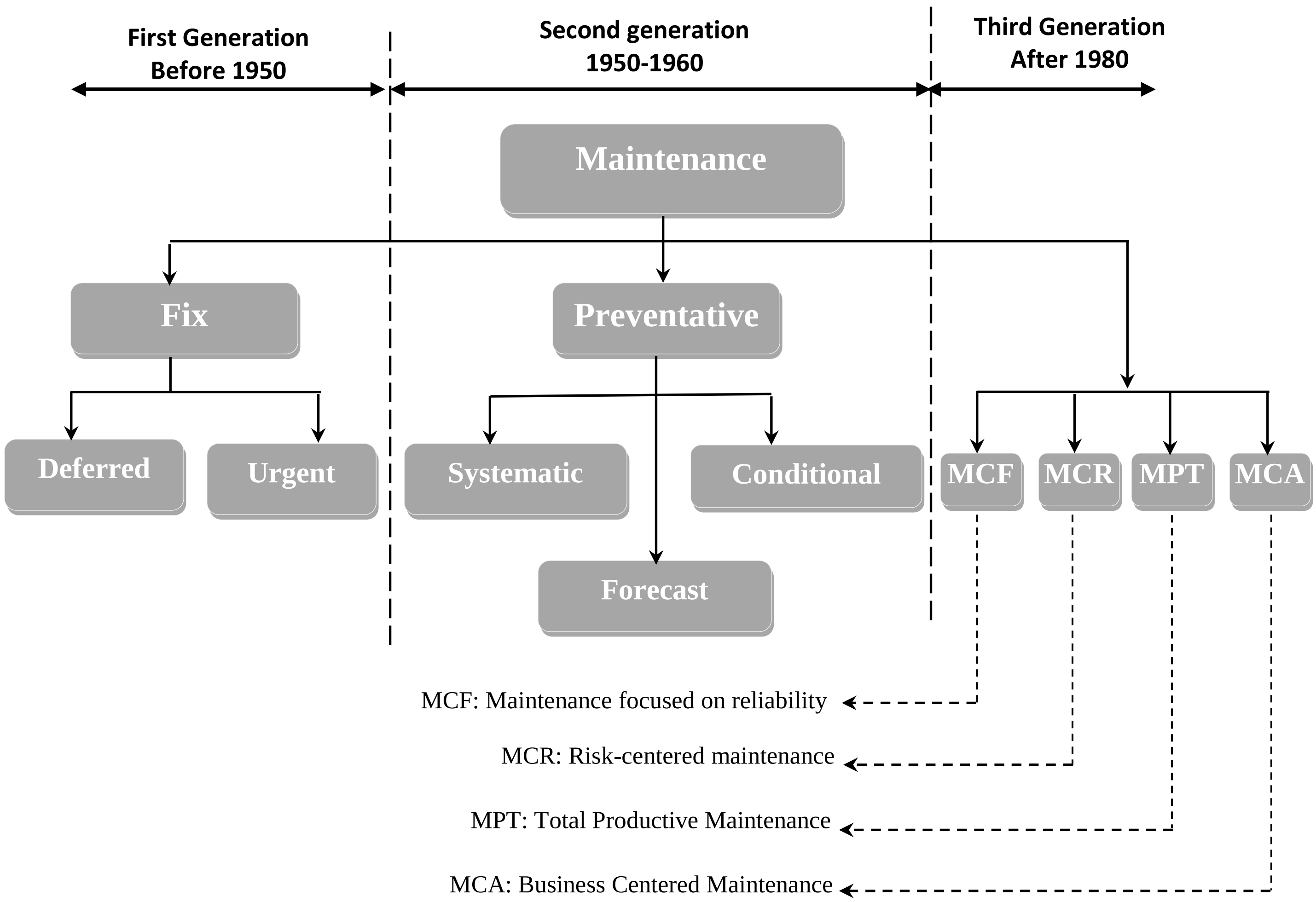

Figure I.6 Development of the maintenance concept

I.6.1 First generation of maintenance: Before the 1950s, the industry began its first steps of development. Mechanization was very limited and the systems were generally simple in design and above all very specific. Furthermore, productivity constraints made it possible to define production strategies that were sufficiently robust to hazards and in particular to breakdown hazards. Furthermore, storage costs, particularly for spare parts, were not necessarily taken into account in the value of the assets. Maintenance strategies essentially consisted of operating systems until failure and then repairing or eventually replacing them.

The first maintenance approach can be described as corrective maintenance, where no measures are taken to prevent failures or to detect the occurrence of a failure. It is executed after detection of a failure and intended to restore an asset to a state in which it can perform a required function [6]. Corrective maintenance can be:

- **Deferred**: maintenance is not carried out immediately after detection of a fault, but is delayed in accordance with given maintenance rules.
- **Urgent**: maintenance is carried out without delay as soon as a breakdown is detected in order to avoid unacceptable consequences.

Corrective maintenance costs are generally high, but this approach can be considered cost-effective and is still applied in areas where safety constraints are low or on systems not subject to aging.

I.6.2 Second generation of maintenance

The end of the 50s is synonymous with the beginnings of the consumer society. This is reflected in particular by an evolution of technology in number and complexity to meet the growing demand for goods, energy and transport. Mass production industries must face increasingly tense markets which require them to be more responsive and productive. There are three types of preventive maintenance:

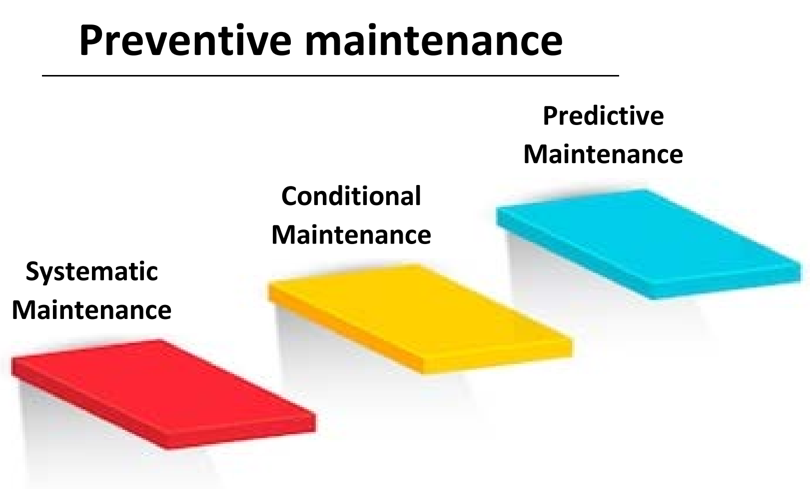

Figure I.7 Second generation of maintenance

The exploitation of new energies is subject to stricter security requirements in terms of control of these means of production and the same is true for transport in view of their multiplication and the development of air transport. In terms of maintenance, this also translates into better control of production systems and the definition of the first preventive maintenance policies. Preventive maintenance is defined as activities performed at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or degradation of a system [7].

I.6.2.1 Systematic maintenance. It is the first form of preventive maintenance which appeared in the 1950s and 1960s. It is executed at pre-established time intervals or according to a defined number of usage units with the aim of completely or partially restoring the required function of a system. The maintenance operation is carried out in accordance with a schedule determined a priori which takes no account of the state of the system. It is interesting for systems with low maintenance costs, monotonous productivity and a low level of security. In the 1970s, the evolution of science and technology motivated the integration of information technology in the field of maintenance. The appearance of sensors and monitoring systems marked the birth of two new concepts: condition-based maintenance and predictive maintenance which began mainly in the aeronautical and defense industries.

I.6.2.2 Condition-based maintenance. This is preventive maintenance whose actions are based on monitoring the operation of the system and/or significant operating parameters. Significant operating parameters are characteristic measurements of systems such as vibration, temperature, degree of erosion, quality of lubricant used, etc. Operation and parameter monitoring can be performed on a schedule, on-demand or continuously. The intervention decision is then a function of critical thresholds which are determined upstream.

I.6.2.3 Planned maintenance: This is a special case of condition-based maintenance. It is executed by following the predictions extrapolated from the analysis and evaluation of significant parameters of system degradation.

The difference between predictive maintenance and conditional maintenance is that we do not set thresholds for the indicators but the decision is based on the analysis of the evolution of these indicators during the entire operating process of the system. In the industrial environment, the combination of preventive maintenance and corrective maintenance is both necessary and implicit. Indeed, preventive maintenance can reduce the probability of failure but will not be able to completely control failures which occur randomly.

The increase in the number of preventive interventions, Figure I.7, makes it possible to reduce the costs and impacts of uncontrolled unavailability of the system but causes an increase in the overall cost through inspection and execution costs. preventive maintenance. One of the challenges for management is to find the optimal balance.

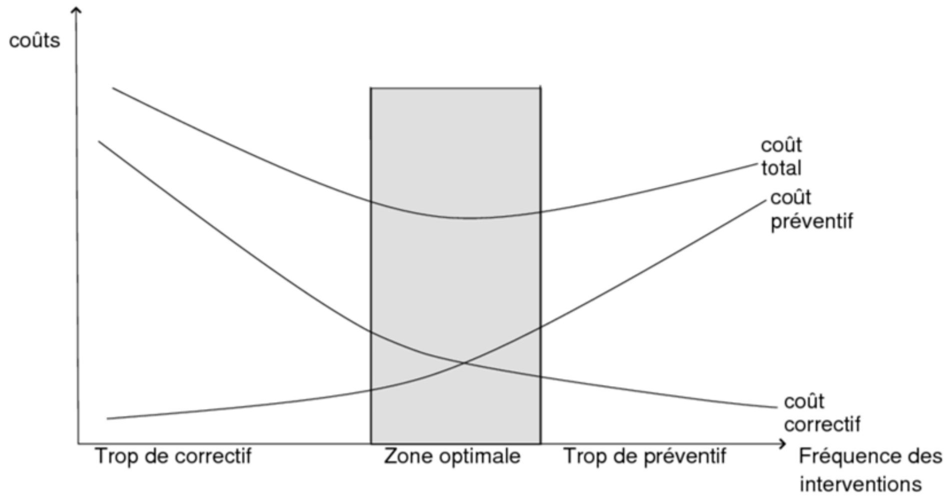

Figure I.8 Balance between corrective and preventive maintenance

I.6.3 Third generation of maintenance: The third generation of maintenance approaches is mainly linked to the constant search for business competitiveness and especially the reduction of production costs. It becomes necessary to carry out maintenance as closely as possible according to the different performance criteria and therefore to prioritize actions and identify the causes of failures almost systematically.

This is the very principle of this new generation, the two main ones of which are reliability-centered maintenance (RCM - Reliability Centered Maintenance) and risk-centered maintenance (RBM - Risk Based Maintenance). These approaches are based on knowing the true state of the system, searching for failure modes and taking proactive actions aimed at eliminating the causes of failure.

I.6.3.1 Reliability Centered Maintenance - RCM: This third generation maintenance approach seeks to maximize system availability at the best possible cost, by carrying out the right maintenance at the right time. RCM was first applied in the aviation industry. Then, it is used by many industries such as the naval industry, the chemical industry, the nuclear industry, etc. It also appears in the property management sector [8].

I.6.3.2 Risk-centered maintenance - RBM: Its objective is to better understand the risks and ensure compliance with the requirements prescribed by the safety authorities at the best possible cost. It is of interest in areas where failure can cause very serious consequences such as the production of nuclear energy. Indeed, RBM is first offered to passive equipment in American nuclear power plants and follows the rules defined by the American Society of Mechanical Engineers (ASME). In recent days, its application has expanded in several industrial fields (petrochemicals, chemicals, paper, steel, energy,) which want to improve their economic efficiency while respecting safety and environmental criteria.

However, RCM and RBM focus on the technical aspects of failure and maintenance operations without integrating the organizational dimension. We then seek to improve the responsiveness of maintenance through the search for organizational efficiency. This involves the creation of internal and external partnerships between maintenance and other departments of the organization. Thus, a new concept of maintenance appears which can be described as a business organization-oriented process. Total Productive Maintenance (TPM) can be considered the representative of this group. A key innovation of TPM is that operators take greater responsibility for basic maintenance - so-called autonomous maintenance.

I.6.3.3 Total Productive Maintenance – TPM: Was initially defined and implemented in Japanese companies. It is causing fundamental change at all levels of the organization – from the lines of operators to the highest levels of management. In other words, with the concept of TPM, maintenance becomes a complete philosophy which included a plan of activities for the life of the equipment, and a process of continuous improvement involving all individuals and all departments [9]. Indeed, the organization of the TPM must be designed for all company departments because it must be integrated into their actions that the company is pursuing. It is presented in Figure I.9.

The organization of TPM is based on a method of monitoring production processes in real time through monitoring of system operating parameters and product quality tests. Furthermore, production data must allow the early detection of minor breakdowns as well as pre-diagnosis of major breakdowns. Still at the operational level, TPM recommends an autonomous maintenance system which includes simple activities carried out by operators for their own equipment or workstations. These activities may include cleaning, lubrication, minor adjustments and troubleshooting, etc. At the tactical level, maintenance management includes three important missions: troubleshooting large complex systems, implementing scheduled maintenance and improving the management of production processes and maintenance logistics.

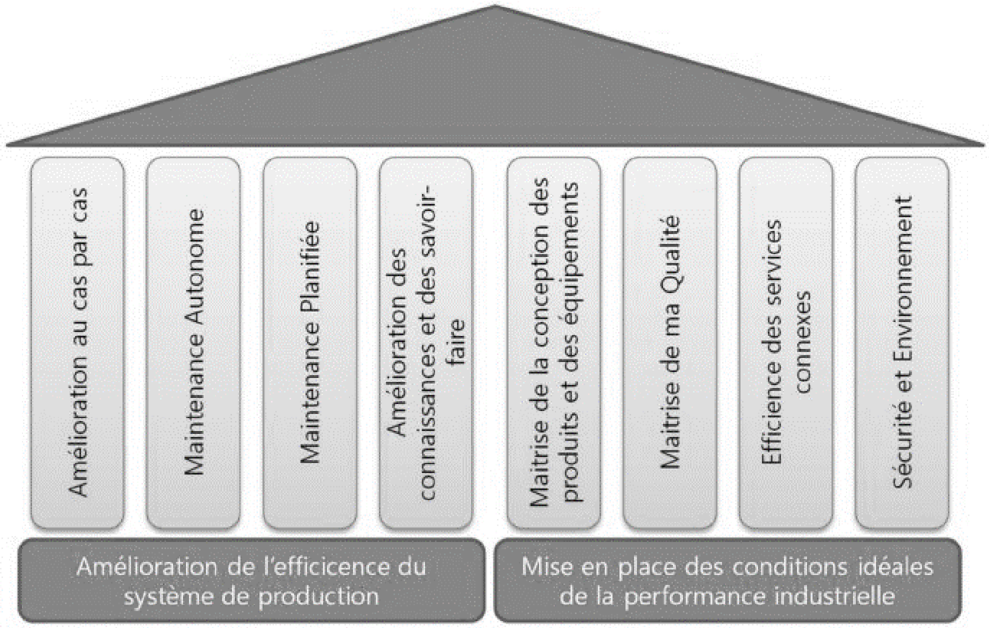

Figure I.9 Organization of the TPM

The philosophy of TPM takes its origins, like the other approaches previously mentioned, in the technical/technological analysis of maintenance based on consolidated feedback (we will not talk here about CMMS - Computerized Maintenance Management Systems - which participate in the centralization of these databases) and which then opens to other company processes. We can then speak of bottom-up methods. Another more economic approach can be to consider maintenance as a real business project integrating the strategic objectives of the company and their translation into maintenance strategies. This is the principle of Business Centered Maintenance (BCM) which can also be seen as an evolution of TPM. The details of the BCM presented in the following section refer to the work [10].

a. Focused improvement

The Focused Improvement pillar is basically synonymous with Kaizen, the Japanese organizational philosophy focused on implementing incremental improvements. Characteristically of Kaizen, all personnel involved in production are encouraged to pay attention to, look for, and suggest improvements. The ultimate goal being, naturally, to reduce production-related issues and keep the line flowing.

b. Autonomous Maintenance

Autonomous maintenance enables operators to fulfil duties that would normally be performed by maintenance personnel. It stimulates frontline workers to take ownership of their machines and perform routine maintenance practices like cleaning, inspection and lubrication (CIL) tasks. This pillar connects operators to their machines and allows engineers and maintenance teams to focus on tasks that require a higher level of expertise. Autonomous maintenance enables operators to detect faults early and tackle minor issues before they develop into large problems. Over time, implementing autonomous maintenance will have a big impact on shop floor performance.

c. Quality Maintenance

This TPM pillar aims to reduce quality defects and, consequently, the need to rework defective products. The ultimate goal is to increase production efficiency, eliminate rework-related costs, and improve customer satisfaction. Defects can be managed through RCAs and by implementing preventative measures like digital production start-up checklists.

d. Planned Maintenance

Breakdowns can be prevented by scheduling maintenance activities when a machine isn't scheduled for production. This ensures that maintenance has no impact on the flow of production. Closely related to autonomous maintenance, this pillar lets operators perform maintenance tasks to free up time for maintenance and engineering teams.

e. Early Management

This pillar enables a fault-free and smooth implementation of new equipment and machinery. By applying the knowledge gained through the application of other pillars (e.g. autonomous maintenance), the installation and start-up time can be lowered, while maintenance is done properly from the start.

f. Training and Education

Naturally, investing in the continued education of operators and management will enable to manage the increasing complexity of modern machinery. This sixth pillar encourages managers to survey the capabilities in their factory. This gives them an overview of the present skill and enables them to make substantiated investments in training and education.

g. Safety, Environment, and Health (SHE)

This pillar aims to create a workplace that is free of any hazards and safety risks. It can be corrective as well as preventive: Corrective actions fix something after it has happened, while preventive actions proactively look at possibly unsafe situations and mitigate them before they turn into an accident.

Next to the elimination of accidents from the shop floor, this pillar seeks to create a work environment that is healthy for its workers, both physically and mentally. Attention should be paid to issues like air quality, proper workload, available facilities and so on.

h. Administrative TPM

Last but certainly not least, the Administrative TPM pillar includes aspects of an organization outside of the shop floor, like logistics and planning. It aims to apply the TPM philosophy to other processes within a business to, just like with equipment, eliminate waste and cut costs.

I.7 CONCLUSION

In this chapter, we recalled the basic concepts of maintenance which plays a vital role in guaranteeing the availability of systems. By analyzing the process of development of maintenance concepts through the evolution of maintenance practices in an industrial context, we note that, under the influence of systematic mechanization and the pressure from manufacturers for maximum exploitation of their maintenance systems production under the constraints of safety and respect for the environment, the objectives and recognition of maintenance are evolving within the company. It is no longer a sole source of expenses for troubleshooting and must be better connected and recognized by all other organizational processes. We briefly highlighted the interest in jointly considering the interests of maintenance and the definition of investment strategies in new assets. However, such consideration is not easy, especially since the decision-making contexts in which the systems evolve are complex, in the sense that they integrate a very large volume of information of various natures and potentially of a contradictory nature, and highly uncertain.