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ORGANIZATION OF THE MAINTENANCE - METHOD TO IMPLEMENT A MAINTENANCE MANAGEMENT SYSTEM AND METHODOLOGY FOR EFFICIENT MAINTENANCE ON HEAVY MACHINERY

Relatório de Dissertação do Mestrado em Engenharia de Produção

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Resumo

Este trabalho dá início à construção de um método para implementação de um sistema de gestão da manutenção e é também um estudo de organização e disponibilidade de máquinas pesadas.

A pesquisa tem como fundamento base a manutenção e todas as questões inerentes a esta. Irá descrever e salientar a importância da manutenção e resolução de problemas nos dias de hoje nas empresas. Para o sector específico da manutenção de máquinas pesadas, apresento uma proposta de organização com o objetivo de fazer melhor uso dos recursos humanos e materiais.

O trabalho será apresentado como um estudo de caso geral.

Perante os modelos existentes de manutenção, a realidade, o propósito / finalidade, princípios e ferramentas, apresento novas perspetivas de como atuar e desenvolver o trabalho que permita encontrar a melhor forma de fazer a gestão da manutenção eficiente e eficaz.

No desenvolvimento do trabalho é importante conhecer todas as variáveis da manutenção porque apesar desta ser planeada podem existir e / ou verificar-se desvios do planeamento, o que acontece com alguma frequência. A criação de uma metodologia de implementação de um sistema tem como objetivo não só a sua implementação, mas também a eliminação de falhas e a procura da melhoria continua.

Após conhecer bem a manutenção é tempo de começar uma nova pesquisa para o desenvolvimento do sistema em si. Na continuação deste trabalho, serão criados procedimentos e apoio à decisão, a fim de sustentar a organização da manutenção e o sistema de gestão da mesma. Este estudo foi realizado para três tipos de equipamentos: escavadora, máquina florestal e pá carregadora de rodas).

Palavras-chave: Manutenção, Máquinas Pesadas, Organização da Manutenção, Sistema de Gestão da Manutenção.

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Abstract

This paper is the beginning of the construction of a method for implementation of a maintenance management system and a study organization and availability of heavy machines. It is a research of base fundaments of maintenance and all the issues that arise from the maintenance. It will describe the importance of maintenance on these days to the companies and their problems with maintenance. A specific sector, maintenance of heavy machinery with the proposal to organized, to make better use of human and material resources, will be presented as a general case study.

Given the maintenance models, the reality, the end of destination, principles and tools, a new perspective, how to act and develop the work in order to find the best ways to perform the maintenance management in an effective and efficient manner will arise.

It is important to know all the variables of maintenance. Because even if maintenance is planned deflections of the plan can be possible and that happens very often. The creation of a methodology to the implementation of the system aims its implementation and therefore the elimination of waste and always looking for improvement.

Now that we know well the maintenance the question is the time to begin a new research for the development of the system itself. On the continuing of this work procedures and decision supports will be created in order to sustain the maintenance organization and the maintenance management system focussing on specialised equipment's (excavator, forest machine and wheel loader).

Key words: Maintenance, heavy machinery's, maintenance organization, maintenance management system

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Abbreviations and Acronyms List

CEA	*Cause Effect Analysis*
CPM	*Critical Path Method*
FMEA	*Failure Mode Effect Analysis*
FTA	*Fault Tree Analysis*
KPI	Key Performance Indicator
MMS	Maintenance Management System
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
OHS	Occupational Health and Safety
PDCA	Plan Do Check Act
PERT	Program Evaluation and Review Technique
PMO	Preventive Maintenance Optimization
RCM	Reliability Centered Maintenance
TPM	Total Productive Maintenance

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List of Symbols

λ – Failure rate

A – Availability

R – Reliability

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Chapter 1

Introduction

This chapter is describes the objectives, relevance and importance of the issue, addressed in this report.

Maintenance is an essential and even the day-to-day of our lives, whether in the personal or businesses scope. This chapter intends to show that this study, the creation of a methodology to implement the maintenance management system is important for companies. And the benefits that brings the application of this tool.

Also points out what is the focus of study and the target companies.

1.1. Problem definition

Many company's don't have a properly system of maintenance organization. Maintenance is not static, can change the service, new equipment's, change of production, new policy, etc. For example, if the company have a service of rent with some maintenance organization, but they want to expand to sales of machinery and consequently maintenance after sales. In others words, the work of maintenance will grow and have to be readjust. So the main idea is doing a double use of the new service after sales and rental maintenance. We have to improve what already exist and / or creating from the root.

The question that arises is: What is the best methodology to create a system of maintenance, to adopt, for the companies of heavy machines?

1.1.1. Objectives of the study

1.1.1.1. General objective

This work intended to provide a proper Maintenance System to the workshops, with application in a maintenance study of heavy machines.

1.1.1.2. Specific Objectives

A system of maintenance can be created by the root or can be an upgrade for the existent. This study intends to serve for both the situations, for example if the company:

1. don't have any commitment with maintenance; this methodology can be applied from the root, assuring that the maintenance will be fully organized.
2. have a part or parts of a system of maintenance; this methodology will help to complete their existing system.

What is intended is a creation of a methodology to give the company a complete and integrated system of maintenance. A system which can make better use of human and material resources. Combining the maintenance, to be more effective and efficient. And able to improve over the years.

1.1.2. Relevance of the study

This study will be important for any company, because independently of the level of commitment to maintenance this methodology intends to adapt and complete what exists.

This is a thematic of high interest to any company that has a service of maintenance. The application of a system of maintenance is always relevant to a company. Maintenance is a large share of costs, a system when properly applied as a result of reducing the costs of maintenance. Reduce costs is a great goal for any company.

1.1.3. Meaning and importance of the issue

The market is more and more competitive, the development of economic policies and other measures that encourage fast/efficient and effective response by the companies dealing with a generalized increase in interested parts of concerns about the issues of maintenance.

Therefore organizations try to achieve and demonstrate a solid performance of maintenance, by monitoring the processes and taking into account there's political and maintenance goals.

The implementation of a maintenance system can and should be integrated with the management of other aspects of the organization's performance, in order to:

- Reduce maintenance costs;
- Minimize risks to employees and others;
- Improvement the organization's performance;
- Help the organization to create an image of responsibility and commitment;
- Help the organization to be competitive in the market.

The methodology will be designed to provide the organization with elements for a efficient system, which can be integrated with other management requirements, in order to help the organization to achieve the goals.

1.2. Case of study

Any company that provide heavy machinery; technical assistance, maintenance and repair; the occasional transport of goods; rental with or without driver.

A Company it has a fleet of machinery and equipment to suppress their customer's needs, providing a rental/sale service with effective and quality.

Standard heavy equipment categorization, by type:

1. Track-type;
2. Grader;
3. SkidSteer;
4. Excavator;
5. Backhoe;
6. Timber;
7. PipeLayer;
8. Scraper;
9. Mining;
10. Articulated;
11. Compactor;
12. Loader;
13. Track Loader;
14. Material Handler;
15. Paving;
16. Underground;
17. Hydromatic Tool;
18. Highway.

Figure1.1 – Examples of heavy machinery according with list above (adaptation) [unknown]

As mentioned in previous paragraphs, the focus is on the organization of maintenance of these machines. This type of machines are very specific and with high costs of maintenance. These are the company's “production”, is very important to keep them in the best possible condition. Therefore it's very important to perform the maintenance, to keep the fleet in service and satisfied customers.

The case study is directed to the maintenance sector with the pretension of improving the service of this type of companies.

1.3. Document structure

Chapter 1, introduction, is presented a brief approach to the topics to be developed in the following chapters, as well as the motivations and relevance of the study.

Chapter 2, literature review, addresses to several strands of maintenance management. It is intended in this chapter to give a global idea of important areas and maintenance aspects in order to understand better the study case.

Chapter 3, case of study, in this chapter is presented a method to implement a maintenance management system and methodology for efficient maintenance on heavy machinery. In order to demonstrate the potentiality of the application of the methodology, is used indicators to evaluate the results.

Chapter 4, presentation and discussion of results, presents some considerations and analysis of the results demonstrated by the calculated indicators and the work that can be developed in the future.

Chapter 2

Literature Review

This chapter aims to address primarily maintenance management itself, the service strategic use, since nowadays market is very competitive and businesses survival depends on companies' ability and readiness to innovate and perform continuous improvement.

A nowadays maintenance framework and the maintenance department position at the company is made. Are focused significant maintenance aspects of maintenance methods types; maintenance cost; documentation support and performance indicators relevance in maintenance decision.

It shows a Preventive Maintenance Optimization (PMO) program study is also analysed demonstrating that combining a wise operation with careful maintenance, production reliability with low cost can be provided and that this should be the basis for an artful management of decision making process in maintenance management.

The maintenance of heavy machinery is a specialized area that has its peculiarities. Not only is it important to choose the type of machine for the type of work, as well as it is important to maintain and take account of what is needed to keep these machines in operation. The maintenance is based on preventive maintenance and especially in the periodic inspection and testing equipment periodically. Is very important that operators are highly qualified. By maintaining machinery frequently it will extend its life and increase its performance.

The maintenance organization seeks the excellency of the maintenance service. The top management have to be involved on this organizing and managing procedures, resources, planning, maintenance performance, verification and analysis of the work. Based on the management of these topics and developing of these, will give a maintenance service excellence and space to improve continuously.

After organized maintenance is necessary a connection between the company and the client, adding a continuous improvement cycle. The proposal is to use a maintenance management system to archived excellence, to make maintenance most effective and efficient, and that it meets the client requirements. To start this implementation it is essential information gathering, assessment and comparison. This process is called auditing. It is intended with this type of audits, information collecting that will give the starting point for the necessary planning adjustments for proper changes implementation.

2.1. Introduction

Any equipment undertakes a deterioration process. In order to keep the equipment functions to which it was conceived it is necessary to maintain it in good functioning conditions.

During his lifespan the equipment has: repairing, inspections, items substitution, routines, among other activities/tasks. In industrial activity maintenance is one of the most important, as this "contributes to productive performance, safety, quality product, good interpersonal relationships, company image, economical profitability of productive process and investment preservation" [1].

Nowadays market "oscillates" a lot and a company's survival depends on her ability and innovating readiness to preform continuous improvement. Therefore, companies continuously search new management tools that improve their market competitiveness, outbringuing, among others their services; processes; productivity and quality. This work of search / adaptation / implementation implies big agility and eficiency in decision making wich implies constant changes within the company [2].

In a company, the Maintenance Service or Department relates to the company's constituting areas. As shown in figure 2.1 maintenance correlating areas with maintenance are:

1. Purchase;
2. Quality;
3. Occupational Health and Safety (OHS);
4. Production/Manufacture;
5. Warehouse and stock management;
6. Commercial;
7. Case Studies;
8. Human Resources;
9. Financial Resources.

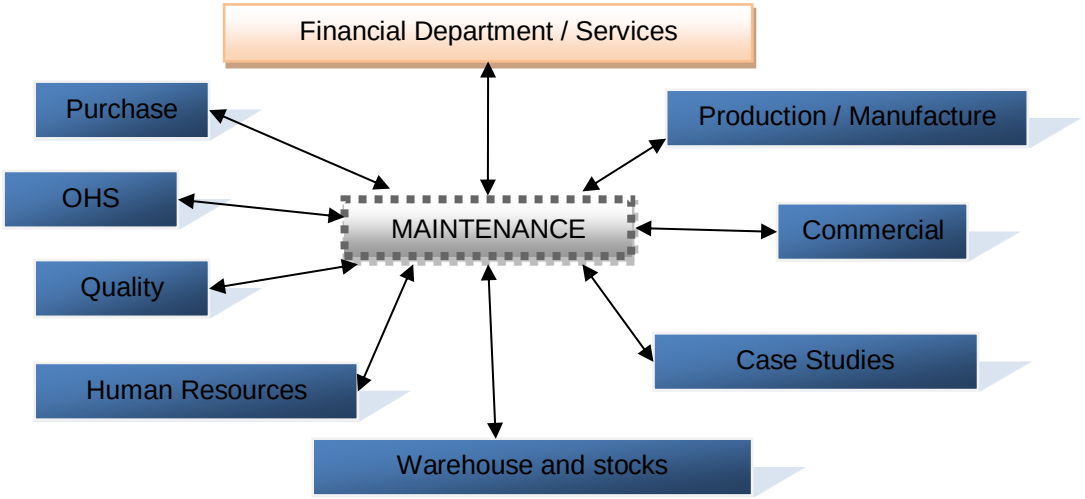

Figure 2.1 – Maintenance and other company areas relation chart (adapted) [3]

Due to market demand, maintenance searches new ways to think because as the needs of an industrial equipment maintenance are based on three aspects: maintenance has come searching new ways of thinking due to market demands, as an industrial equipment maintenance is based on three aspects:

1. An equipment maintenance always represents a production function(despite these tasks different responsibilities);
2. There is a connection betweeen fabrication technologies and tools to the equipment's maintenace;
3. The economic efficiency of maintenance activities / interventions should be linked to productivity of each equipment, as well as the quality [4].

Excellence in service is sought by companies and reflects the existing competitiveness between these anywhere on the globe. Offering quality products at attractive prices, delivery schedules, and therefore considered a reliable supplier, the more familiar term is "world class".

To have success in line with productivity, is implied maintenance as a contributing factor. Concluding that the management of maintenance has to be meticulously thought [4]. Good maintenance gives confidence to production, stimulates the technicians to focus on what's important, opens new career opportunities and improves security [1].

The choice of a maintenance method has to match maintenance policy and in accordance with the company's directive. It is necessary to know the objectives of the company but also to understand the operation and characteristics of the material, as well as the conditions of each method application, and not forgetting the costs of maintenance and lost production [3].

Maintenance management, will plan the implementation or improvements in the existing maintenance system, going to implement the planned measures; monitoring the results of actions taken either previously or subsequently with the information derived from monitoring.

Having said this it is considered that Plan Do Check Act (PDCA) cycle of Deming can be adopted. This is used to achieve results within a management system and can be used in any organization to ensure goals achievement.

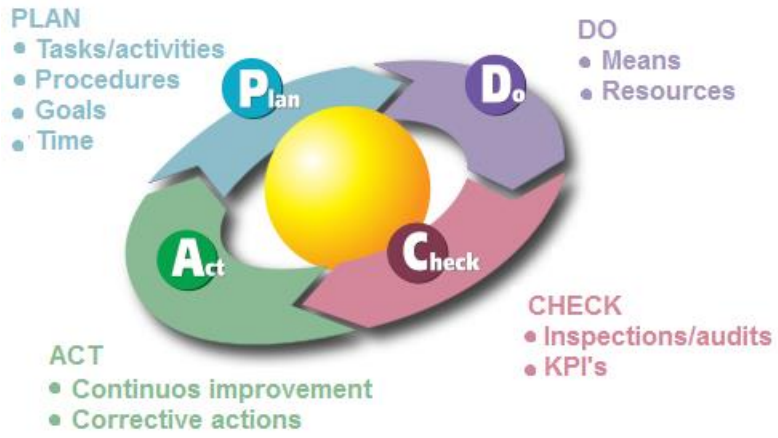

Figure 2.2 - Deming Cycle (adapted) [5]

This is a dynamic process that with the effort of management and employees, may only result in continued improvement in company's maintenance area performance.

Such System implementation to the company is important to demonstrate/ensure their commitment to any area of your internal policy. Succeeding in improving the efficiency of internal operations and consequently "waste" reduction and elimination, improving thereby the work environment.

2.2. Maintenance

According to the Portuguese standard (NP EN 13306:2007) maintenance is a combination of all technical, administrative and management during the life cycle of a good, actions to keep or replace it in order to perform its required function [6]. To get good performance is essential to define goals and organize maintenance and is there that maintenance management enters, that means by all management activities that determine objectives, strategy and responsibilities concerning the maintenance and that are implemented by various means such as planning, maintenance control and supervision and organization methods improvement, including economic aspects [6]. Within this management there are maintenance plans so that everyone knows when/how and where to intervene. The maintenance plan is the structured tasks that include the activities set, procedures, resources and time needed to perform maintenance [6]. However it is necessary to the ability of a maintenance organization to provide the appropriate means of on-site maintenance necessary to perform the maintenance activity required at a given time or over a given time interval , which is called the maintenance adequacy [6]. Maintenance can be performed by company internal resources or by providing external expertise in order to enable equipment to perform the actions, conceiving or organizing maintenance management can prove to be a task composed of some complexity.

To assist in this task there is the Portuguese Standard NP 4483:2009 – *Guia para Implementação de Sistema de Gestão de Manutenção* (Guide for the implementation of the maintenance management system). This standard assists and advises in designing a system for the company maintenance management providing internal customer service with own and / or subcontractors means enabling company will set a maintenance policy that allows them to achieve performance objectives of their processes, offer not exhaustive securities that the company may add, delete, modify or adapt according to the scope of the maintenance management system and provide the maintenance management system to be effective. In designing this system, referred in the standard, approach of Deming cycle is used [7].

2.2.1. *Maintenance Types and Strategies*

As previously stated the method and strategy of maintenance depends on the company policy for maintenance. You must know the company, it's operation and equipment characteristics and application conditions for each maintenance method.

The diagram below represents several existing maintenance methods, parameters that cause the maintenance operations and operations themselves.

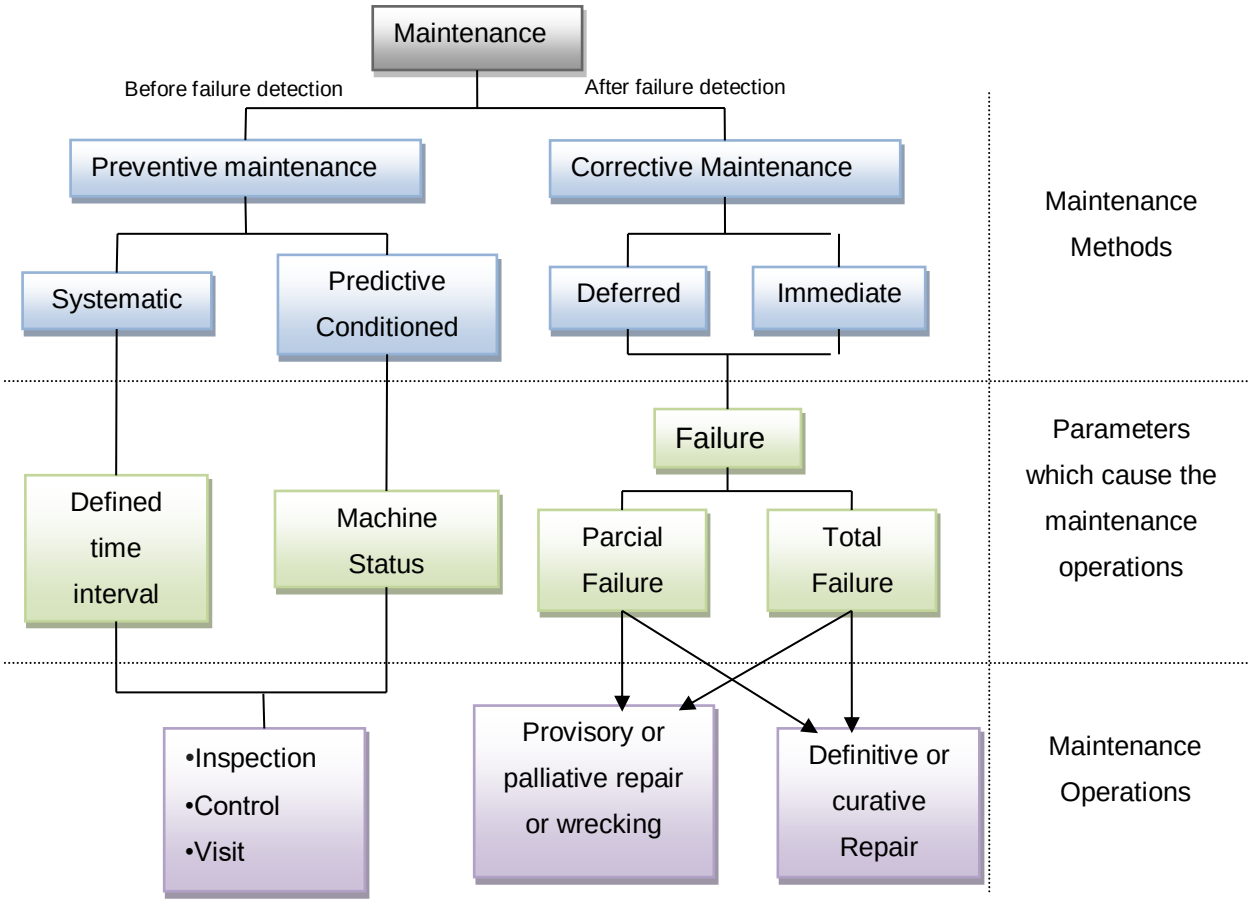

Figure 2.3 - Diagram of methods and maintenance operations (adapted) [6] [8]

Preventive maintenance is scheduled to run at predetermined intervals of time, according to an established criteria for the equipment and / or its components, in order to make equipment reliable. This type of maintenance can be systematic or conditioned / predictive.

A systematic preventive maintenance is performed in pre-established time intervals or according a defined number of utilization units but without previous state control of the equipment , this is realized by was so determined in maintenance strategy [6]. While conditional preventive maintenance is already supported in monitoring the equipment functioning and parameters are significant for the proper functioning, completing the actions resulting therefrom, vigilance on the operating parameters can be carried out according to a schedule, requested or continuously [6].

The conditional predictive maintenance is carried out according to extrapolated estimates from the analysis and evaluation of parameters significant in the equipment / component degradation [6].

Corrective maintenance is the maintenance performed after detecting an equipment or component malfunction. Once fault is found, this service aims to repair the equipment / component.

Immediate corrective maintenance is considered an equipment / component urgent maintenance, this is effectuated after failure detection to avoid disastrous consequences.

Deferred corrective maintenance is a maintenance that is not immediately performed after the fault detection as it is considered that failure does not interfere with equipment operation goals, being this maintenance delayed according to certain rules of maintenance by the company [6].

In the diagram shown in Figure 2.4, there is a maintenance operations division, which is the maintenance achievement itself.

As maintenance operations we have:

1. Wrecking (provisory revision);
2. Inspections;
3. Repairs;
4. Visits;
5. Controls;
6. Revisions;
7. Substitutions;
8. Among other.

Maintenance which are performing maintenance properly said. There are activities related to the operations and complement referenced maintenance actions, such as:

1. Modification;
2. Renewal;
3. Reconstruction;
4. Further work;
5. Security;
6. Among other [9].

The following table is a maintenance operations summary involving the mentioned maintenance methods above.

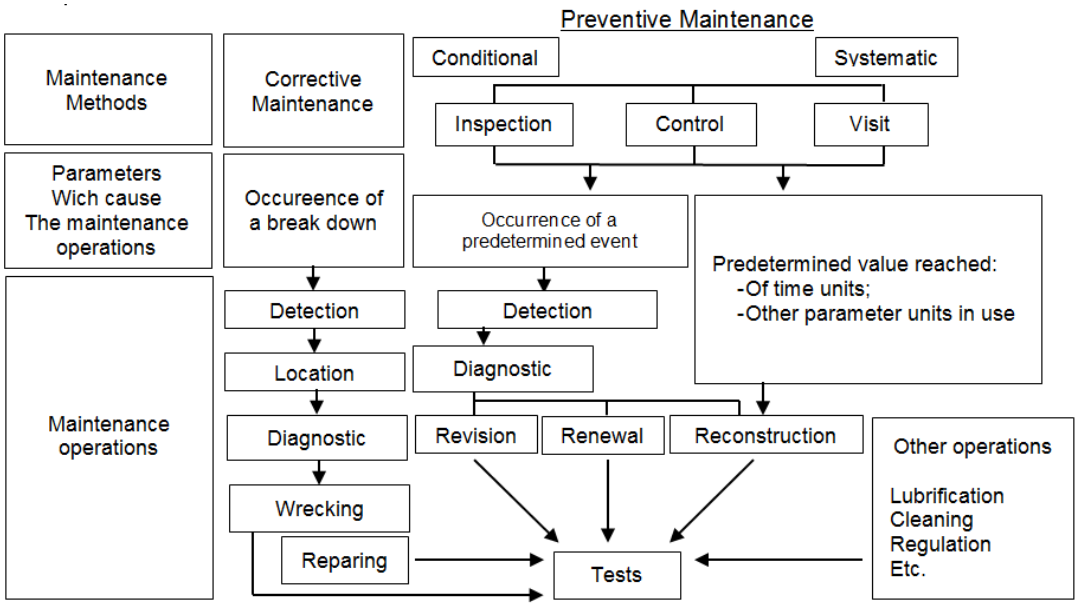

Figure 2.4 - Operations Maintenance [9]

The way you use these methods is called the maintenance strategy and this strategy changes depending on the policy that the company has to maintain. The maintenance plan is designed with possibilities and availability knowledge, stimulating the most of information and knowledge to perform maintenance efficiently and effectively.

2.2.2. Maintenance Costs

Maintenance is a service that serves production, taking also into account the persons and property safety, to ensure equipment availability at minimal cost .Cost reductions are possible if each equipment maintenance is studied, allowing work preparation; ensuring equipment availability of at the time, of tools; materials and work method definition.

In maintenance is important to equate long, medium and short term plans. Are predictions of what might happen, based on historical and knowledge (know-how) [9].

The medium-term forecasts intend to maintain the company ability, ensuring equipment immobilization at times that do not disturb or minimize the production loss, requiring a previous work program [9].

The long-term predictions relate to the company's policy, allowing workload estimatives, stocks and investments. When talking about short-term forecasts, these correspond to the appliance of maintenance programs to each device, considering the fixed assets reduction need and interventions cost [9].

When we think of maintenance costs, always remember the hand labor, materials and any contracted services. Hand labor reflects in Man per Hour or Man per Day. Materials are parts or material, purchased or stock, to be applied in repair / replacement. Service is meant by hiring other companies to perform specific character work or hand labor lack. These costs are considered direct

costs, considered more into account and are visibly consequent of performed maintenance. However there are other costs beyond those described as for example not visible costs. Figure 2.5 is a maintenance real costs iceberg graphic representation that testifies there are indirect costs that can be four times larger than direct costs. In this submerged region costs which appear are not easily quantifiable, called indirect costs and these can be for example: accidents, production stop, income, environmental issues, late deadlines, product defects, maintenance which lead to more interventions, administrative, training, energy consumption, storage stocks, among others [1] [3].

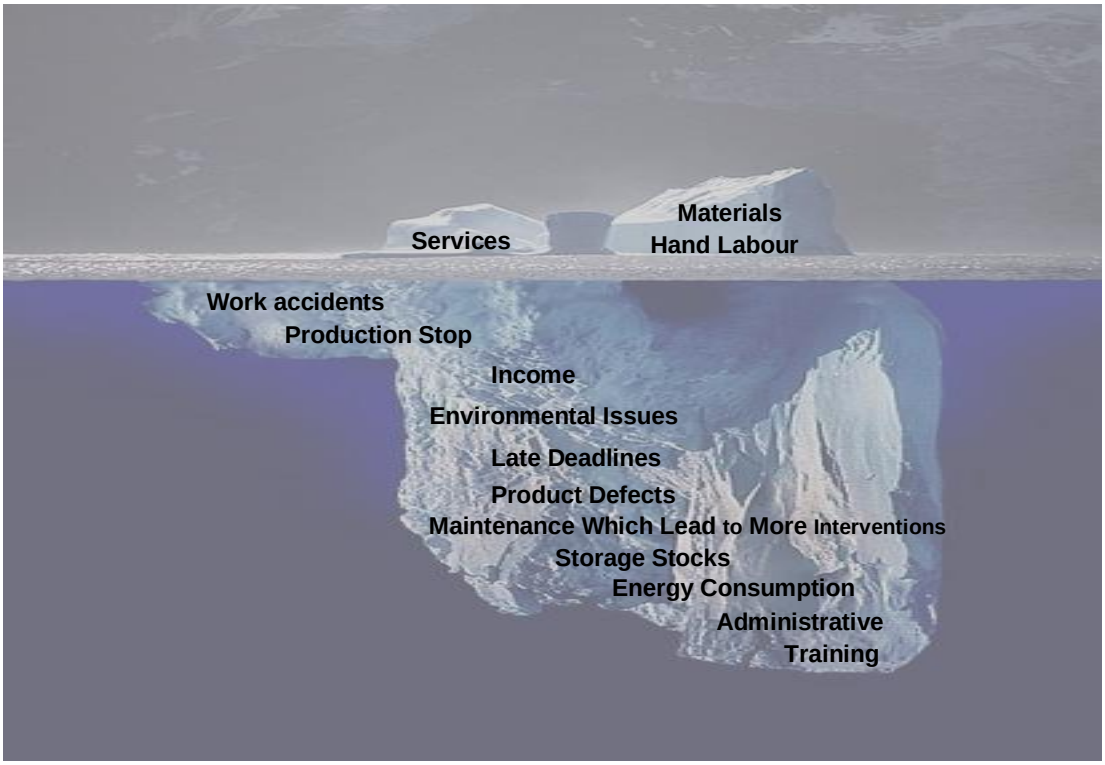

Figure 2.5 – Costs Iceberg (adapted) [1]

Generally maintenance budgets are made based on previous year's budget with the following adjustments:

1. Material and services increase;
2. New maintenance policy introduction;
3. Phase startup of new equipment.

New equipment always have large upfront costs due to testing and start-up costs which come to be 50 % higher than average rates in respective industry [3].

Considering practical aspects it is necessary to determine economic maintenance work volume or level, interventions must be made at the right time and labor cost reduction should be tried, as materials and all tasks at a lower level without safety and quality bleach [9].

Diagram shown in figure 2.6 is used to determine maintenance economic requirements. Ordinate shows planning degree and abscissa maintenance costs percentage, expressing planned and unplanned maintenance costs as total costs before breakdown trend.

Performing costs sum of doing or not maintenance, we obtain maintenance total cost.

Planned maintenance cost expresses preventive maintenance cost and lost production cost due to machine immobilization for maintenance performance.

Unplanned maintenance cost includes repair cost, loss production cost due to immobilization for equipment repair and the cost due to the quality degradation (if applicable).

In total cost trend line is a minimum that represents volume or maintenance economic level [9].

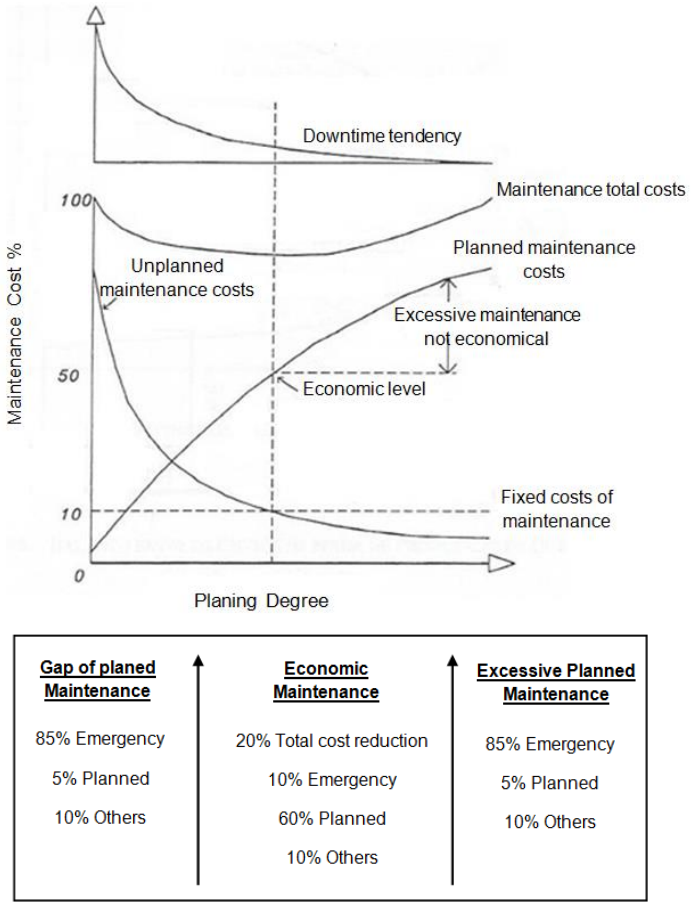

Figure 2.6 - Maintenance costs diagram [9]

Figure 2.6 shows that there should be no deficit or planned maintenance excess. Since planned maintenance reduces immediate maintenance, contributing to downtime reduction, hence greater equipment availability results in increased production. On the other hand production cost increase considering that there is an excess of planned maintenance which does not contribute to economic equilibrium.

Maintenance cost records should be made to allow results analysis, trend in downtime and its causes, in order to establish maintenance economic level.

Minimizing maintenance costs should be based on a ratio between planned maintenance and non-implementation maintenance. Having due regard to production standards so that quality and safety are maintained.

2.3. Management of maintenance methods

The diversity and complexity of maintenance problems from various practical situations have led to numerous concrete models and policies. While it is not possible to come up with a generic model that is capable of describing all interesting situations and scenarios, it is feasible to generalize and reorganize the conceptual models under a unified maintenance modeling framework based on the essence of these problems.

Things to be in mind when we talk about maintenance:

1. The cause of the problems;
2. The frequency of occurrence;
3. The total effects, both loss of production and maintenance cost.

2.3.1. Maintenance tendency

Within many industries maintenance costs can account up to 40 % of the operating budget. Due to maintenance high costs, strategies are thought to improve maintenance efficiency, in order to reduce costs.

Competitive environment lived today requires industries to try support full production capabilities, minimizing capital investment. From maintenance point of view, this involves equipment reliability maximizing including prolonging equipment life. Combining a wise operation with careful maintenance, you can provide reliability in production with low cost. Which is the basis for an astute management in the decision making process [10].

Much of maintenance work done by teams is unnecessary, unproductive or even counterproductive. Many of typical maintenance activities are unnecessary, such as equipment routines, or not needed preventive maintenance [11]. It is necessary and important to review the preventive maintenance activities. There are several review methods; one of the most required is Reliability Centered Maintenance (RCM) that is based on analysis of failure. This type of approach “generally ignores the existing preventive maintenance activities and compares results with existing maintenance programs after the analysis is complete” [12]. “Another method of performing a review of preventive maintenance is a “reverse RCM” process in which each activity is reviewed and tested for its purpose, value and possible duplication against other activities” [12].

Steven Turner presents the results of a study about an approach called Preventive Maintenance Optimization program (PMO); show that preventive maintenance: only 13 % of existing preventive maintenance activities were considered of value; 19 % of preventive maintenance activities were a waste of time and 30% of preventive maintenance activities were made too frequently [12].

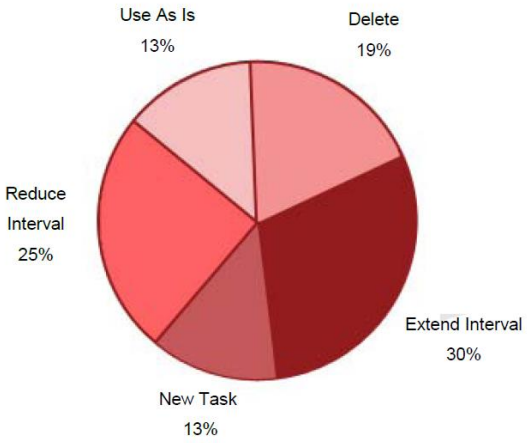

Figure 2.7 - Results of a typical Preventive Maintenance Program (PMO) [12]

This example demonstrates problem extent of over maintenance and shows an assess program effectiveness to preventive approach in maintenance activities.

This study shows that 30 % of effort is wasted in preventive maintenance and other 30 % is detrimental to the equipment and that only about 6 % of the equipment follows a pattern based on bathtub curve shown in figure 2.8, the period of wear.

For most other equipment, over 90 % of faults which occur are usually cumulative effects of events or conditions which occur at any time. This means we can be doing preventive maintenance without need, as we may be doing it too late [11].

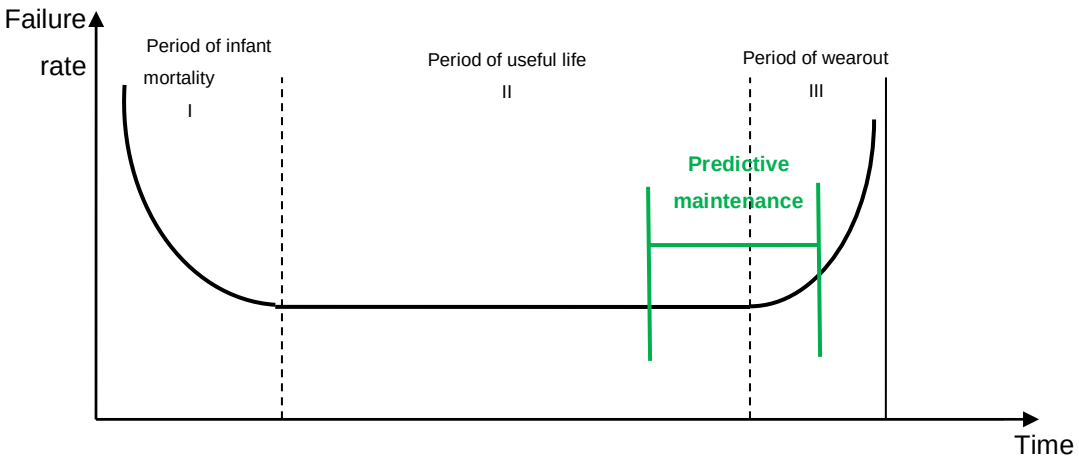

Figure 2.8 - "Bathtub" Curve [13]

The frequency of preventive maintenance is in accordance with deterioration rates or failure rate and operational strategy (windows of opportunity).

It is assumed that as the interval between preventive maintenance activities frequency increases, this activity cost increases. It is also assumed that failure probability decreases with maintenance frequency increase. Figure 2.9 shows a probability and frequency diminishing return [12].

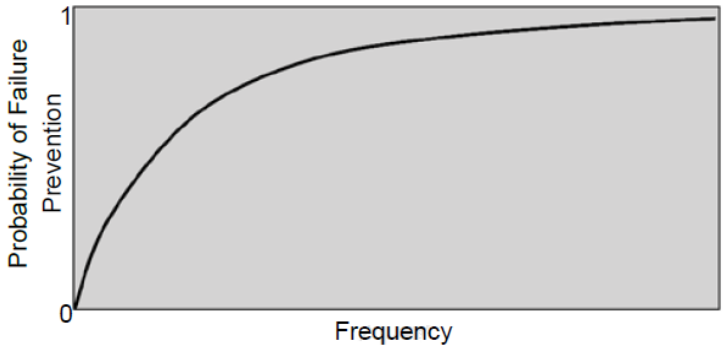

Figure 2.9 - Relationship between probability of failure prevention and frequency [12]

Preventive maintenance can occur too early and / or create new problems. This has two characteristics, an activity to be performed and another that is the frequency with which the activity is performed.

"Residue" reduction in preventive maintenance can achieve both the activity itself or its frequency [6]. If maintenance frequency increases, the probability of introducing a fault and also increases the likelihood of maintenance activity success, is reduced, as shown in Figure 2.9.

Comparing figure 2.9 and 2.10, these provide the argument basis to avoid excessive preventive maintenance frequency.

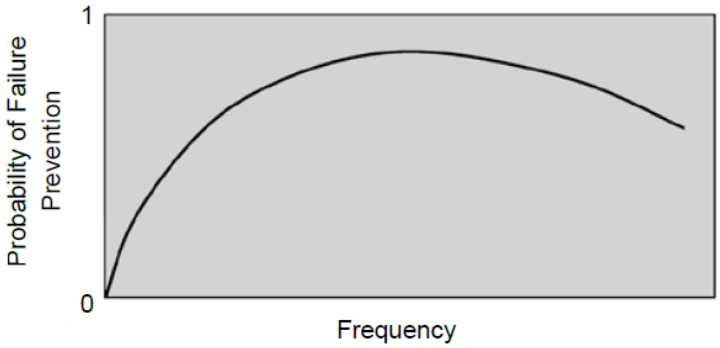

Figure 2.10 - Relationship between probability of failure prevention and frequency [12]

Looking at Figure 2.9, it seems possible to reduce preventive maintenance frequency without having great impact on the equipment reliability. Figure 2.11 shows a significant frequency reduction which results in a failure probability smalls reduction, demonstrating that it is not reasonable to decrease frequency.

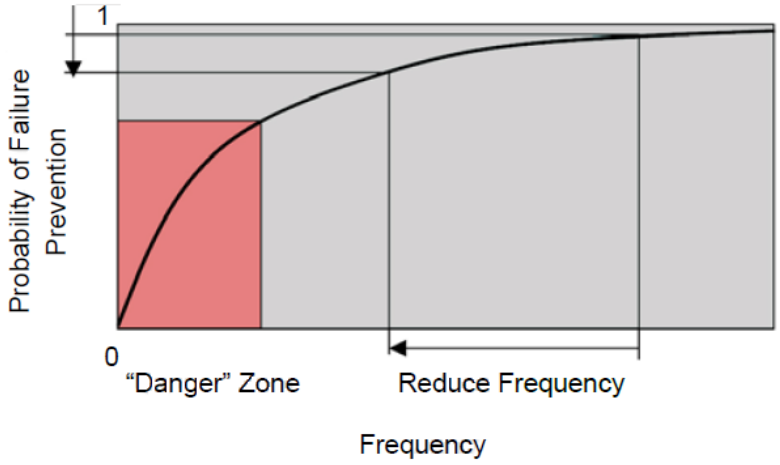

Figure 2.11 - Maintenance frequency reduction effect on assets reliability [12]

The challenge is associated with frequency reduction or increase and when there is a history it may be easier to define a range. However, with no history the decision will have to be consonant, with what is done in equivalent equipment and "know-how" of the decision maker.

As can be seen in Figure 2.11, there is a danger zone that represents proportional frequency decreases to reliability decrease, which is not a desirable situation. Reducing frequency will only be a good strategy as failure probability is low [12].

Industry has taken a conservative stance in its approach to preventive maintenance intervals. Studies on the intervals practiced arrived at the following conclusion:

• 80% of costs are spent on preventive maintenance activities with a 30 days or less frequency;

• 30-40% of costs are spent on preventive maintenance on equipment malfunctions considered negligible [12].

Predictive maintenance is a "preventive maintenance based on monitoring the well and/or significant parameters of operation itself, integrating resulting actions [13]. After testing and non-destructive measurements (which are made periodically to obtain information about equipment condition), data are analyzed and evaluated in order to understand what is the equipment condition, and thus provide the decision making to repair the equipment based on actual data and the planning before failure. This method improves production and reduces maintenance costs and downtime.

Proactive maintenance creates connective actions that turn objective the root failure causes, not just symptoms. The goal is not just to avoid a catastrophic failure but restore or even improve equipment performance. The future will be even betting on this kind of maintenance since this presents a better efficiency.

For efficient maintenance will be necessary to make a correct balance between three main maintenance types above (predictive, preventive, corrective). Figure 2.12 shows traditional maintenance and current maintenance percentages use.

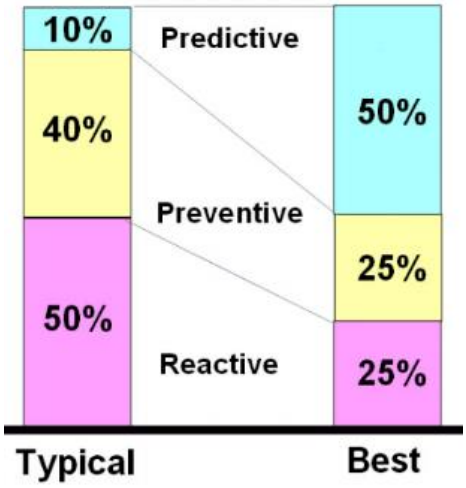

Figure 2.12 - Use of maintenance. [11]

Current tendency to carry out maintenance works most in predictive maintenance, causing greater preventive maintenance frequency ranges.

Predictive maintenance equipment control, can also improve corrective maintenance situations.

It's better to consider preventive maintenance only when:

1. Corrective maintenance cannot be justified;
2. Predictive maintenance cannot be applied;
3. "As required" maintenance effects cannot be tolerated.

2.3.2. Methods

The maintenance has types and strategies, for practical application, as known, but is necessary to organize them, in order to take more advantage. So we use methods to organize and obtain a more efficient maintenance.

2.3.2.1. Reliability Centered Maintenance (RCM)

Reliability Centered Maintenance has as main objective to generate improvements, optimization of costs and efficacy. Among its features are the preservation of equipment function, identification the failure modes that affect the function, prioritization of job requirements, and it makes it through the failure modes and classifies activities maintenance to be effective, improving the availability, reliability and system security.

RCM understands that exist definition of the system or equipment to be analysed, and its borders/interfaces; functional analysis of each component of the system or equipment; analysis of failure modes and effects; use of decision trees for definition and selection of maintenance tasks; formulation and implementation of maintenance plan [3].

This methodology must be fooled by this model:

1. First identify the critical faults of equipment in a systematic and properly structured way, and its consequences on the security of goods / people / environment and in a continued production;
2. After the identification, using a specific methodology, it is necessary to determine the most advantageous maintenance policy to be applied in each of the equipment taking into account the risks assumed by the consequences of the damage and costs that includes labor, spare parts, redundancies. [3]

In this methodology are included systematic preventive maintenance, conditioned maintenance, inspections to control the function conditions, inspections to safety and protection equipment's and redesign of components and equipment's. [3]

RCM have as principle that the inherent reliability of a machine is on the quality of project and construction, while the maintenance ensure this reliability, but she does not increases. In this sense, this increase becomes possible by redesigning or equipment modifications. Having always in mind has a logical diagram to follow the points that identify the components in the system / equipment that are critical in terms of mission and / or safety.

2.3.2.2. Total Productive Maintenance (TPM)

Total productive maintenance arise from the need to improve the waste, reworks, loss of time and human effort, high costs of the corrective maintenance. With the analysis of this problem, begins a new way of thinking and it started to give more importance to the preventive maintenance. It was developed the concept of total productive maintenance.

This type of maintenance required the participation of everyone, from top to bottom.

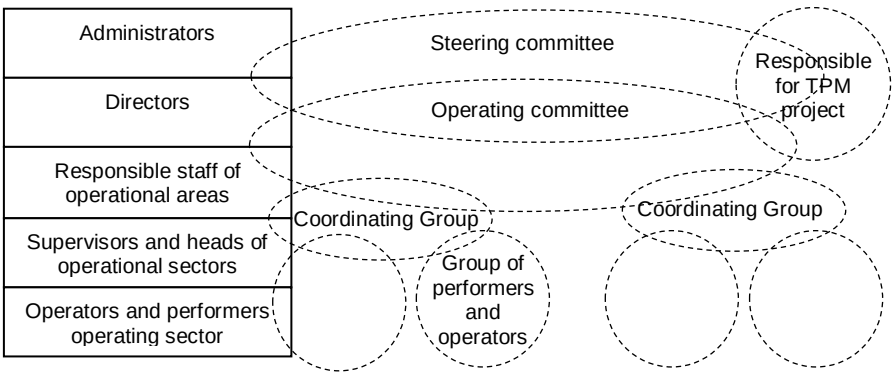

Figura 2.13 - Integration of hierarchical levels of the company in the TPM structure [3]

The main objective is to eliminate the faults, defects and other ways of losses and waste, to have an efficient maintenance. The principal faults considered in the maintenance are:

1. Breakdown / malfunctions;
2. Set-up (change of product);

3. Loss of patterns our tools;
4. Small stops;
5. Velocity fell / time cycle increase;
6. Default products;
7. Start machines [1].

The prime objective of this method is the challenge to have zero malfunctions and is based in eith pillars, as shown in the figure below.

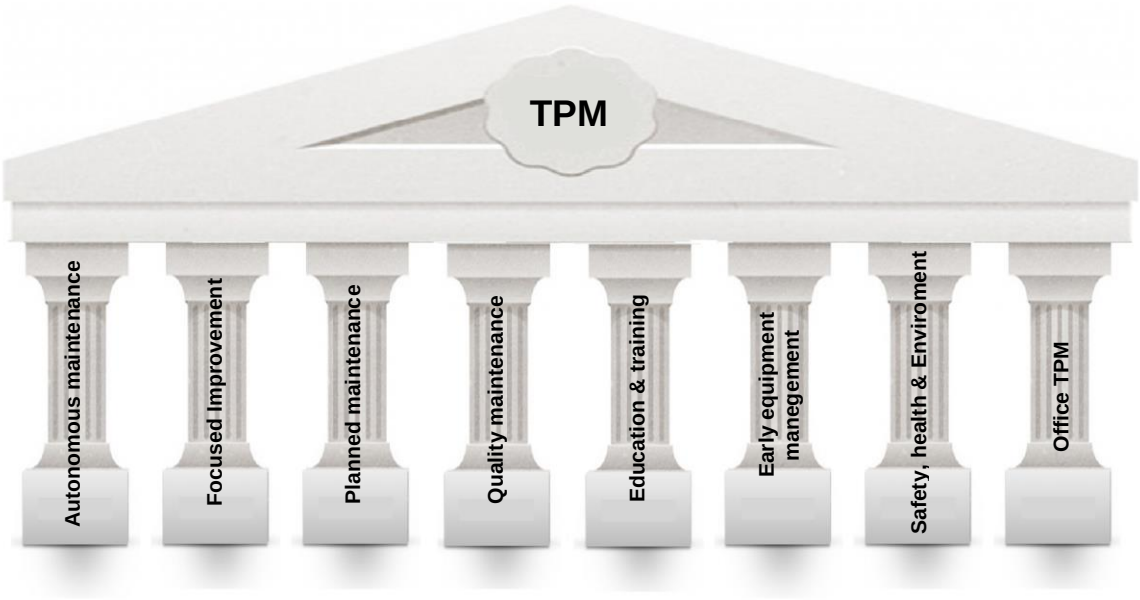

Figure 2.14 – Eigth Pillars of TPM [1]

With the application of TPM the expectable results are:

1. Practically zero malfunctions;
2. Better reliability of machines;
3. Stop times reductions;
4. Less quality defects;
5. Increase productivity;
6. Work accidents reduction;
7. Economize energy and other resources;
8. Rise the work motivation;
9. Pleasant work environment;
10. Company image improved [1].

The TPM implementation must be integrated part of the management objectives and later has to be planned with very careful and be accompanied [1].

This method seeks to blur the traditional and classic structural division of the company functions (production and maintenance) and promote the management of technical assets of global and participatory manner [3].

2.4. Maintenance of heavy machines

Heavy equipment refers to heavy-duty vehicles, specially designed to execute construction tasks. The history of these machines dates back to the ancient Roman engineer Vitruvius (1st century) gave descriptions of heavy equipment and cranes in ancient Rome, wrote in is treatise De architecture. Over the years the development of these machines has been enormous, has gone up from horses, through steam to diesel [14].

The technical advancement of heavy machines during the 20th century includes many improvements in key parts of machines. We are talking of five systems that make up earth-moving equipment:

1. Implement;
2. Traction;
3. Structure;
4. Power train;
5. Control and information [15].

Proper heavy machines selection is a major factor when trying to satisfy a project's budget and schedule requirements. The selection of the equipment is best performed by personnel with experience in earth moving operations [16].

This type of machinery must be target of a good maintenance, inspection, examination and testing of equipment periodically. Always on arrival machine to site, the operator and mechanic should do a check according a check list of the machine after it was unloaded. In this inspection it’s important too now the type of machine, the work it is doing and history of the machine [17].

According with Barton Henderson, too maintain an heavy machine we have to prevent the major problems down the road. He gives five tips for the maintenance of earth-moving machinery:

1. Always keep machinery lubricated;
2. Clean heavy machinery well;
3. Maintain earth moving machinery regularly;
4. Pay attention to wear and tear;
5. Keep Employees trained well [18].

In this type of machines lubrications is very important, because parts will create excess of friction that causes severe wear and tear on the machinery. As a consequence of the deterioration, the lifespan of the parts will be shortened. If we use excessive lubricant the machine will not be able to handle properly causing energy loss, seal issues and accumulation of grease. Not too less and not too much lubrication both will not ensure that the moving parts will operate properly. This machinery’s have parts that are fitted with special seals and filters she as to be clean. The dirty and debris can damage parts. The best way to protect is to keep in a garage or a house. This will prevent of rust, grime build-up and dirty. This kind of issues can create the necessity of repair [18].

The maintenance in these machines is based on inspections and preventive maintenance [18]. It’s important to create checklists, follow a maintenance schedule and a good documented historic. For

example an operator always should do this procedure, normally required particular attention too:

1. Tires;
2. Tracks;
3. Working tool;
4. Linkage;
5. Leaks;
6. Radiator;
7. Reservoirs;
8. Air cleaner;
9. Roll over protection structure;
10. Seat and seat belt;
11. Battery;
12. Other safety features (control buttons, lights and mirrors) [17].

“By maintaining heavy machinery frequently, you will extend its life and increase its performance” [18].

For example: The components of heavy machinery are subject to severe exploration. We must be aware to the signs of wear and tear (vibration), heat and belt shape [18]. Normally expose to abrasive wear, when occurs “non-metallic materials slide or roll, under pressure, across a metallic surface” [19].

The abrasive wear can be classified as:

1. Gouging abrasion;
2. High stress grinding abrasion;
3. Low stress scratching abrasion or erosion [19].

In the abrasive wear, there are two extreme mechanisms of material removal, one which plastic deformation plays a dominant role, and the other in which fracture with limited plastic deformation dominates. According to the simplified abrasion wear theory, equation (Q=N/H), volume loss, Q, is proportional to the applied load (N) and inversely proportional to the hardness (H) of the abraded surface [19].

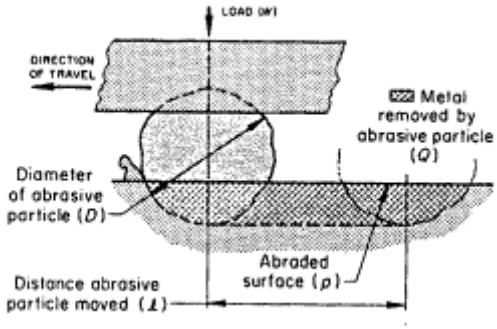

Figure 2.15 - Idealized representation of abrasive wear resulting from mechanical application of force to an abrasive particle. [19]

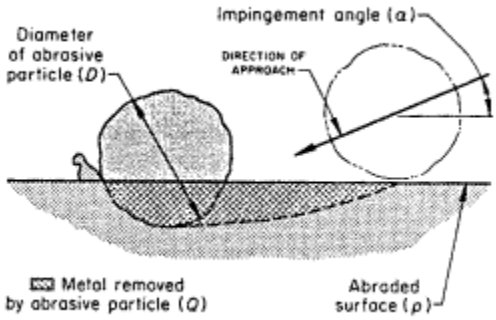

Figure 2.16 - Idealized representation of abrasive wear resulting from kinetic application of force to an abrasive particle. [19]

The hardfacing process, is to be considered, because is a cost-effective tool that can minimize wear and increase service life of the heavy machinery components.

The last tip but not least, keep employees trained well. The heavy machinery's are specific equipment's that have to be skilled at operating it by professionals. In order to protect them all employees must have trained and should be re-trained, to ensure that they now how to operate safely and at current standards [18].

This case of study will focus 3 types of heavy machines:

- Excavators;
- Forest Machines;
- Wheel Loaders.

This typology of heavy machinery work in extreme climatic conditions, random operator's with different skills level of operating, overload of workings hours and short intervals for preventive maintenance. Issues that make it difficult to minimize breakdowns [20].

Is important to stablish and identify: Critical machinery in the "fleet that contribute to major cost and time escalations and to list the critical systems/components and failures on the same"; "root of cause of breakdowns", "classify causes/symptoms and reasons of failure" and "protocols to be followed in during critical breakdowns maintenance" [20].

2.5. Maintenance organization

The maintenance management and organization is a essential good to the success of the company. Will contribute to the safety, quality, production, good relationship, company image, economic profitability and system preservation. Another important element is that maintenance objetives have to be connected to the global objectives of the company.

Any maintenance has the objective to improve the equipment availability but it carry's costs. The target is to find the balance between this two item's (maintenance and costs), this type of management has to reflect judgment. The manager of maintenance has to have good work knowledge of maintenance, planning, staff and material management, general engineering of machines, informatics and leadership [1].

A good management and organization will create expectation that can be used for both sides. To the top management understand the importance of maintenance and take responsibility that will be helpful to the maintenance service to attend and establish their objectives [1]. Is a team effort to achieve the goals.

The maintenance organization have five pillars, as shown in figure 2.19. If these pillars exist, they have to be well organized and properly function to have a good service of maintenance.

Figure 2.17 – Five Pillars of Maintenance Organization (adapted) [7]

2.5.1. Management responsibility

Management responsibility is a commitment of the top management assumes with the maintenance service, maintenance policy. This understands the service need's and creates/allowed the access to the resources. This understanding between top management and maintenance service is very important for the development of maintenance activities.

2.5.2. Resource management

Since the "approval" of top management, the manager has access to resources. The resources for management are:

1. Park (machinery, spares, parts):
   a. Numbering (functional area, identity, cost center);
   b. Logistics base (routable, spare parts);
   c. Storage;
2. Technical Documentation:
   a. Operation manual;
   b. Maintenance manual;
   c. Manual inspections;

d. List of spare parts;
e. Work orders;
f. Reports of damage / work;
g. Historical;

3. Staff:
   a. Intervention areas;
   b. Operators/Drivers;
   c. Training.

2.5.2.1. Documentation

Maintenance, as any other company service performing functions, requires information flow between enterprise services, in order to comply with the objectives determined by the company maintenance policy. Therefore, it is necessary to define documentation flows and documentation to be used in. These documents can be maintenance records (historic, work order, activities, costs, parameters), lists (reference of parts, suppliers); diagrams; control tables; leaves (planning, programming); organizational charts; policies and maintenance objectives; procedures; maintenance contracts; manuals; purchase orders; reports, etc. [21].

This documental organization is fundamental so that maintenance is structured and should be immediately initiated when an asset is acquired. For example when a company buys equipment the supplier must provide necessary documentation for company to carry out maintenance and proper equipment operation. Known as notebook machine, this set must contain technical specification; historical (purchase process, minutes of correspondence, history of work performed); reserves (parts lists, appointments and acquisitions); maintenance instructions (systematic maintenance tasks, maintenance inspections Guests, type preparations); drawings; sub - equipment, etc. [22]. Therefore, there are a number of essential and necessary documents to maintenance. Portuguese standard (NP EN 13460:2009 – *Manutenção, Documentação para a Manutenção*), which suggests a serie of documents with respective elements constitution, adaptable to the specific company needs.

Maintenance workflow is a set of sequential tasks in order to perform a maintenance operation, from preparatory activities, such as study and policy, to analysis after work completion and improvement actions for cases similar future as seen in the following figure 2.18.

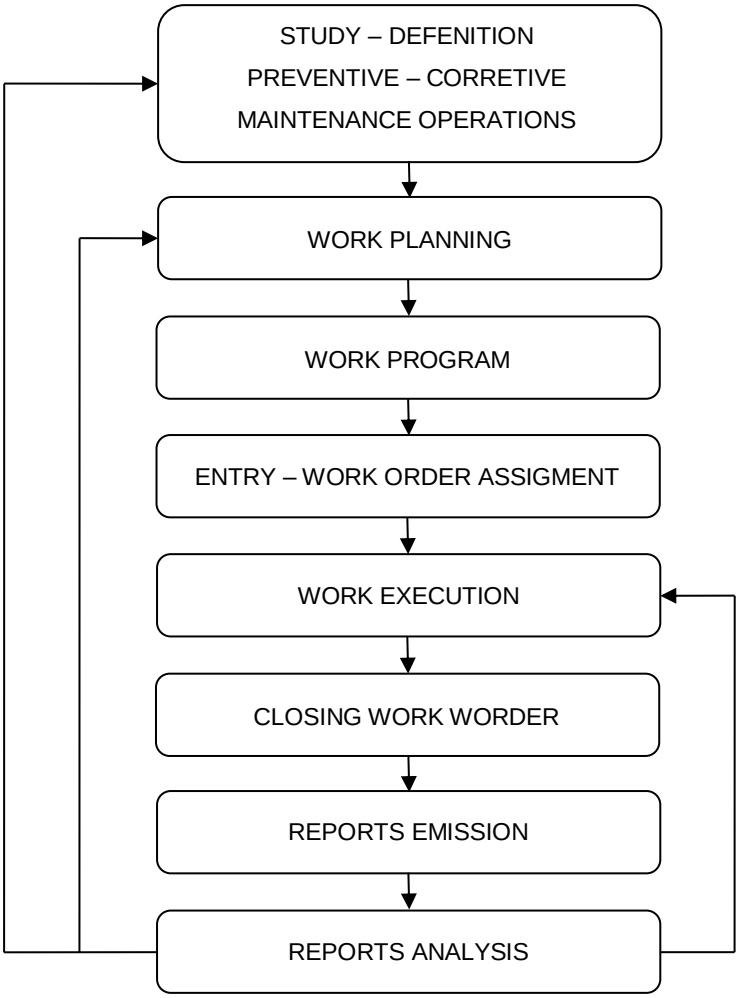

Figure 2.18 - Diagram Maintenance Organization by activity [22]

The work order is the most important to the maintenance organization documents, this is the document that contains all the information related to maintenance activity and links to other reference documents necessary to carry out maintenance work [9]. This is the document that will indicate the need to perform the work, necessary for its implementation, instructions also serve as a record of resources used and their labor costs. It may also prove to be used with the function history of future suggestion of shares [21]. According to the Portuguese standard (NP EN 13460 : 2009) a work order must contain the following information: Number; requestor; date of registration; opening date; closing date commodity code; location of the good; hours of operation of the good; type of maintenance; periodicity; environmental and safety regulations; justification for retention; frequency; date of last operation; calculation of resources; checklist; complaint; faulty piece; cause of the malfunction; technical procedure code; discretion of the performance; amount of labor; type of labor; personnel; reference of parts; amount of spare parts; outside labor; external spare parts; other external services and acceptance.

2.5.3. Maintenance planning

Maintenance planning determines the resources needed to complete a maintenance work. Normally the planning contents overhauls or preventive maintenance that is carried out periodically. The principal objectives are: Minimizing the idle time of maintenance workers; maximizing the efficient use of work time, material, and equipment; and maintaining the operating equipment at the level that responsive to the need of production in terms of delivery schedule and quality" [23].

Each work has a maintenance method, special tool needed, skilled workers required and time to perform. However this is not linear, there are some critical aspects to contemplate. Maintenance have a random variable and there is not always capable of performing the work. There are twelve steps for an effective planning procedure can help the planning:

1. "Determine the job content;
2. Develop a work plan (sequence of activities, best methods, procedures);
3. Establish crew size for the job;
4. Plan the order parts and material;
5. Check if special equipment and tools are needed and obtain them;
6. Assign workers with the appropriate skills;
7. Review safety procedures;
8. Set priorities (emergency, urgent, routine and schedule) for all maintenance work;
9. Assign cost accounts;
10. Complete the work order;
11. Review the backlog and develop plans for controlling it;
12. Predict the maintenance load using an effective forecasting technique" [23].

Planning projects involves developing networks of activities. There are techniques to do the planning, for example Critical Path Method (CPM) or Program Evaluation and Review Technique (PERT).

The planning can be of a long range (five year or more), medium range (one month to one year) and short range (daily and week plans) [23].

Below is shown a flowchart that represents the procedure in the maintenance operation planning. Is numerated by sequential order to follow aims to help to organize the planning, and not miss any element of the planning.

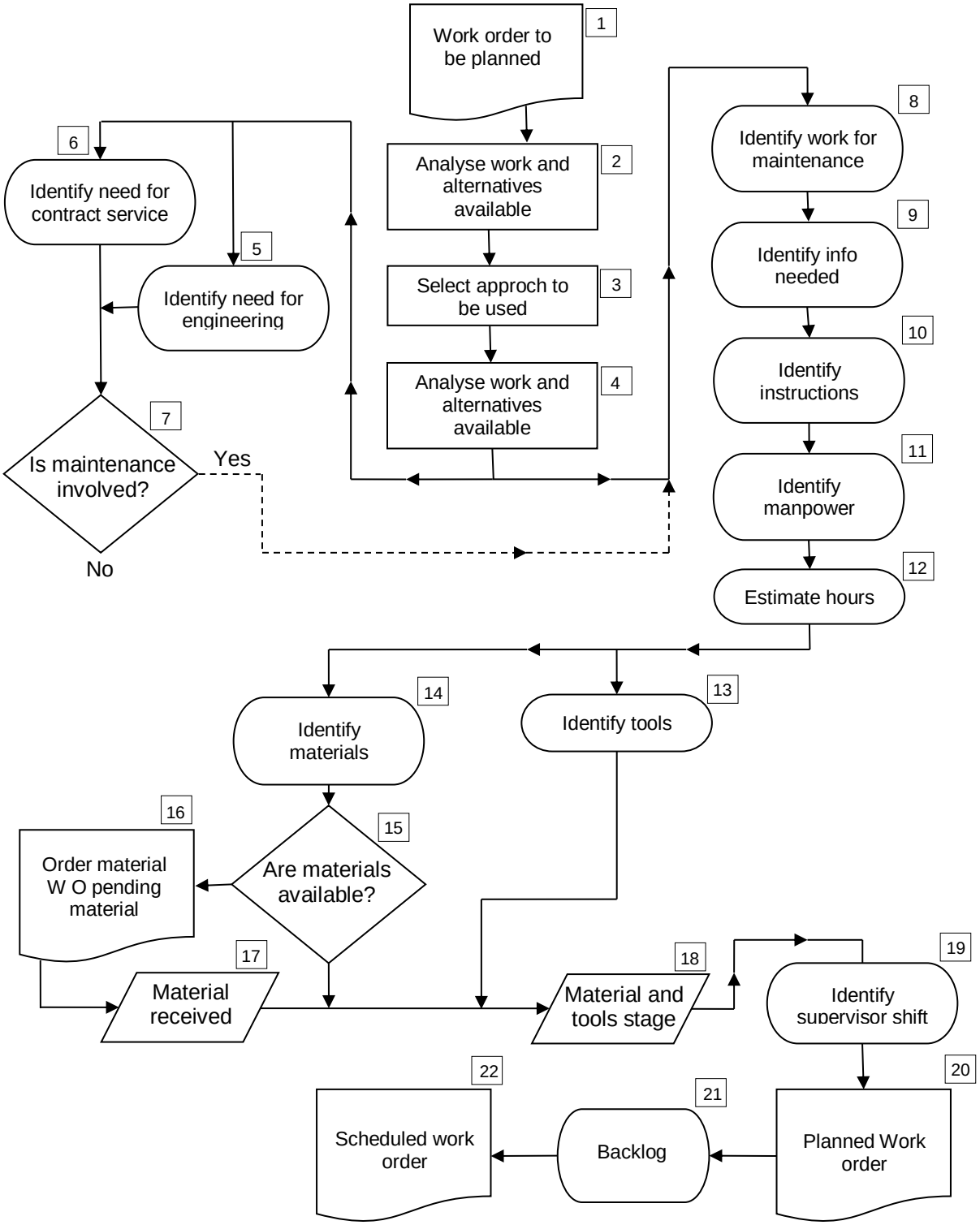

Figure 2.19 - Flowchart for maintenance operating procedures. [unknown]

2.5.4. Measuring, analysis and improvement

This pillar is important, because with the information collected we be able to analyze and draw conclusions for decision support.

There are two way to obtain information, using key performance indicators our auditing. The information's by Key performance indicators provide useful information for decision-making. Audits are a systematic and methodical way to verify the requirements are adequate and/or disabilities is evident. The audit topic will be further developed in chapter 3.

2.5.4.1. Key Performance Indicators

The Key Performance Indicators (KPI) can provide useful information however, they do not always express the whole truth about reality and numerous indicators may exist. However if one asks whether indicator is useful, you should evaluate the following elements:

1. If it helps to make management decisions ;
2. Allow activity comparisons between different years (internal and external benchmarking) ;
3. If possible to assess the benefits of a maintenance policy (analysis of strengths and weaknesses) ;
4. If you have information to prepare maintenance budget;
5. And it should help identify problems , plan improvement actions and continuously measure changes results over time [1] [21].

Portuguese standard (NP EN 15341: 2009 – *Indicadores de Desempenho da Manutenção* (KPI)) describes a management system of indicators to measure maintenance performance. Factors of external and internal influence can be found. Indicators are further divided into economic, technical and organizational [21].

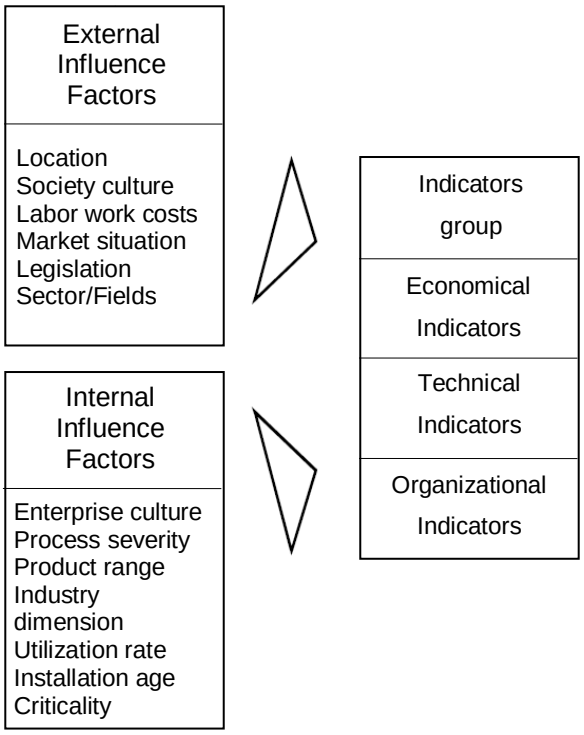

Figure 2.20 - Factors and group of indicators [21]

Maintenance performance is the result of resources efficient use to maintain/restore the condition equipment/component, so it can perform its required function. The indicators are used to assess improvement and efficiency and effectiveness, in order to maintain achieving excellence.

2.5.5. Outside contractors

Some works of maintenance must be performed routinely, other have less frequency and perhaps only once. In these cases is a more profitable hiring external maintenance service.

The enterprises usually have their own specialized personnel in different technology areas of maintenance. However the outsourcing happens when the enterprise don't have their own resources; capacity to execute the work or don't exist the know-how.

On the other side the company that is hired, that provide the maintenance service, must have the care of prospect of job opportunities in the market and marketing their capacities and potential of their services [3].

The outsourcing in the maintenance must be seen as a partnership with the next objectives:

1. Increase profitability of the activity through a bigger efficiency of assets and of lower maintenance costs;
2. Increase the satisfaction on loyalty of the client with lower execution time, more reliable and higher quality;
3. Increase skills;
4. Increase availability for production;

5. Increase the rate of utilization of assets;
6. Low cost of lifecycle;
7. Higher return on investment [24]

In the case of maintenance of equipment, such policy will improve overall maintenance costs through the rationalization of the diagram the maintenance workload; and avoid the need to maintain-house staff with high technical qualifications with a use of periodic or irregular nature.

There is a standard that helps prepare maintenance contracts, Portuguese Standard NP EN 13269:2007. This document has guidelines of important elements for maintenance service contract and their description. It aims to improve service between customer and supplier, improve contract quality, manage conflicts, help in the organization and simplify [25].

2.5.6. Centralization or decentralization

Maintenance can be organize in a centralized, decentralized or both option. This organization will depends of maintenance policy, maintenance load, size of maintenance service, type of activity, requirements of availability of equipment for the production, available human resources and their qualifications, etc.

These options have the main objective of provide more flexibility, improvement on the utilization of resources (special equipment, skilled crafts, etc), more efficacy and efficiency.

	Advantages	Disadvantages
Centralized maintenance	• It facilitates the optimization of human and material resources • optimizing investment in equipment and workshops and their use • facilitates the overall management of the maintenance staff • greater ease in standardization of procedures • greater efficiency in standardization of equipment • better dissemination of information • facilitates better control of contracting work abroad	• Less communication between maintenance and production • Bigger companies is more difficult for immediately calls • Workers less specialized, more difficulty to combined the hardware • Transportation costs increase

Discentralized maintenance	• Introducing greater delegation of responsibility and promotes greater motivation • improves and facilitates the relationship with production • Promotes greater awareness and motivation of maintenance staff to production problems • Improves coordination of interventions and different specialties • Facilitates the transfer of 1ºnivel maintenance functions for production • It facilitates the creation of working groups autonomous production / maintenance	• Loss of vision, each unit is involved only with is own issues • Different criteria of management • Reduce the flexibility of teams, manpower utilization is less efficient • More investment in hardware • The maintenance criteria are guide by production: equipment above is capacity, reducing availability of the equipment for maintenance, increasing the emergency maintenance over the preventive maintenance

Table 2.1 – Centralization / decentralization maintenance, advantages and disadvantages [3]

The type of hybrid (centralized and decentralized) is called a cascade system. “This system organizes maintenance in areas and whatever exceeds the capacity of each area is challenge to a centralized unit. In this fashion the advantages of both systems may be reaped.” [3]

2.6. Fleet organization

2.6.1. Fleet maintenance

When we talk about fleet’s maintenance the primary focus is preventive maintenance. This is the maintenance which can we predict when happens, hours of labor, how many workers and costs. The corrective and predictive maintenance is a “background” of the maintenance in this case but cannot be forgotten. When there is a malfunction or through an inspection is detected an anomaly, is very important to ensure that these repairs are made immediately, in order to increase the machine's life cycle, to prevent worst damage, reduce cost of maintenance, and prevent accidents.

The fleet of heavy machines must have a good planning and well executed preventive maintenance program, this is essential for an economically operated and reliable fleet. “A preventive maintenance program reduces the overall cost of vehicle maintenance and repair, enables vehicles to reach their economic service life, increases the residual or salvage value of the vehicle, and enhances the professionalism and credibility of the fleet department” [23].

On a fleet maintenance we should keep in mind the following factors:

1. Dimension of company;

2. Specificity of the vehicle;
3. Renewal policy;
4. Type of service and type of company or organization as defining the type of the maintenance organization and the use of sub-contracting;
5. Types of sub-contracting and situations that can recommend;
6. Maintenance Organization [26].

Thinking on the keeping the vehicles well maintained and servicing the community, the maintenance must have the next objectives:

1. Maintaining flexibility for changes in route(s), schedule(s), environment, new technology, and other impacts;
2. Maintaining chassis, body, and component manufacturers recommended maintenance practices;
3. Systematic inspections, services, and repairs;
4. Defect reporting;
5. Maintaining the proper level of fiscal control;
6. The proper management of parts, equipment, facilities, fleet, and personnel;
7. If inventory is maintained conduct a 6 month inventory check [27].

2.6.2. Fleet replacement

There is no formula that calculates when it's no longer cost-effective to keep a machine in service. However we can create a comprehensive replacement program based in replacement criteria, thinking in guidelines that must be multi-faceted, contemplating the following factors:

1. Systematic policies and procedures;
2. Maintenance programs;
3. Decision models;
4. Lifecycle cost considerations;
5. Funding mechanisms;
6. Financial projections and analyses [23].

The figure 2.23 represents major phases of lifecycle of vehicles, phase one of the fleet vehicle lifecycle is a vehicle needs evaluation, and the final phase is the remarketing, disposal, or reassignment of the vehicle.

When the organizations are thinking on replacement the management should ask the following question:

1. "Is the vehicle being fully utilized?
2. If the vehicle is not being used, why replace it?
3. If it does need to be replaced, is the current specification of the vehicle appropriate?
4. Would a different vehicle be better suited for particular application?
5. Are there any secondary uses for the vehicle?" [23]

With this question the organization avoid having too many or inappropriate vehicles in their fleet.

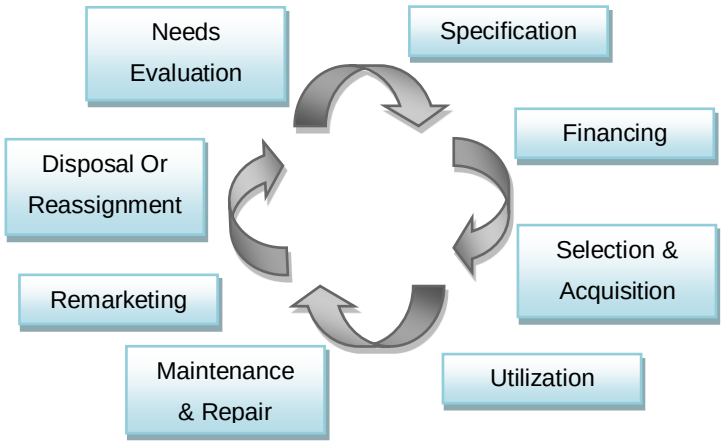

Figure 2.21 - Fleet vehicle life cycle [23]

To take a decision the fleets must be organized, need to have data on utilization of their fleet units (kilometers, hours of engine work, fuel consumption and other parameters considered important) [23].

Sal Bibona show a decision model process for vehicle replacement setting replacement priorities based on alternative level of funding or when funding under constrain. “This approach not only identifies the specific units of replacement, but also actively involves user groups in the process”. The figure 2.22 illustrate the decision process.

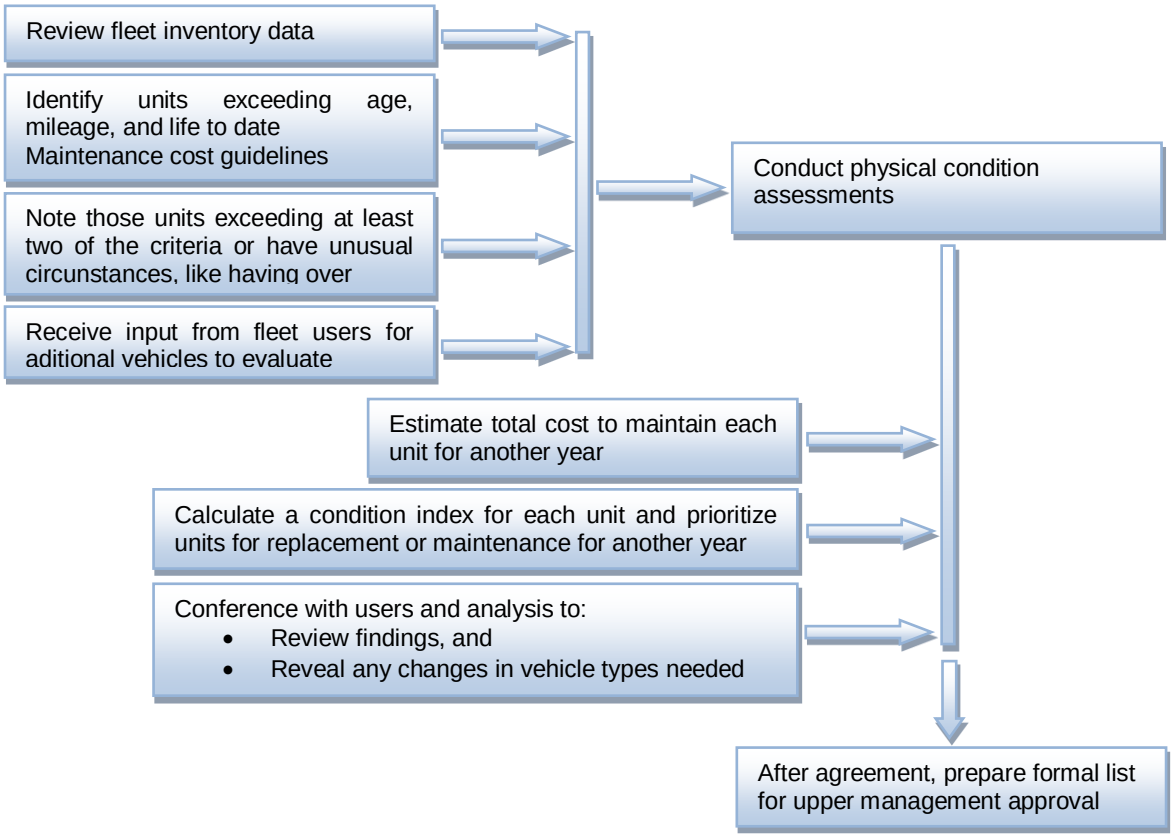

Figure 2.22 - Decision-making process for fleet replacement [23]

The parameters included in the analyze are:

1. Acquisition costs;
2. Estimate salvage value;
3. Cost of money
4. Maintenance costs;
5. Operations costs;
6. Fuel costs;
7. Age or kilometers to date;
8. Downtime cost;
9. Obsolescence cost.

In order to take the best decision the companies must perform a thoughtful analysis of the issue, it important to consider all direct costs, including depreciation and maintenance, as well as indirect costs, including park value, corporate image, downtime, and future upgrades.

2.7. Asset Management

Asset management allowed to companies and other institutions allow to maximize the value of their physical assets. The correct management of asset includes decisions like: planning maintenance, time to replacement or not, investment return, continuous improvement, follow company policies (legislation, standard, ethical, environmental, etc), health and security, sustained growth, satisfaction of all concerned (top management, clients, suppliers and employs) [28]. Asset management is used to get excellency in maintenance. Aims to maximize the effectiveness of an asset during is lifecycle, minimize failures, reduce losses and maximize value.

As is written in the standard, the asset “is an item, thing or entity that has potential or actual value to an organization. The value will vary between different organizations and their stakeholders, and can be tangible or intangible, financial or non-financial”. For manage this assets should exist implementing plan to control and monitories the activities, “to exploit opportunities and to reduce risks to an acceptable level” [29].

Asset management is application of systematic and coordinated activities, by the company, to perform an optimal and sustainable management of assets. All associated to performance, risk and costs, during their lifecycle whit the aim of archiving the strategic plan. In other words is the management of all lifecycle of asset (equipment), from acquisition until is end of use [30].

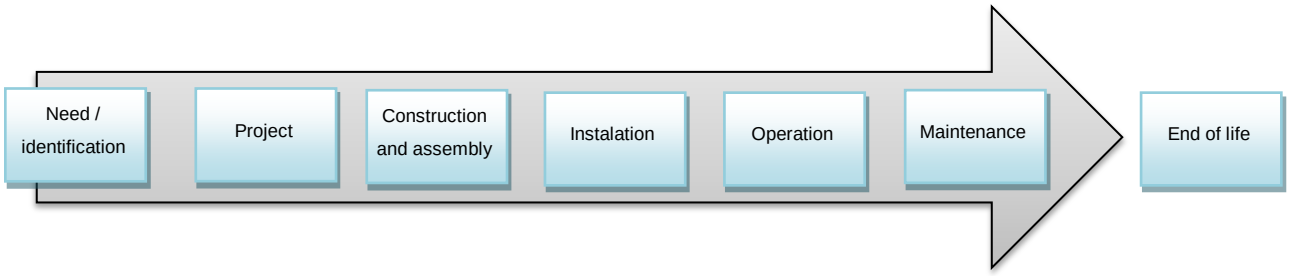

Figure 2.23 – Lifecycle of an asset [30]

2.8. Maintenance Management System

A Maintenance Management System is designed to allow the company to demonstrate its ability to consistently provide a service that meets customer requirements, legal and regulatory requirements. Thereby increasing customer satisfaction through effective application of the system, including processes for continual improvement, based on customer requirements and regulatory requirements, illustrated in figure 2.24.

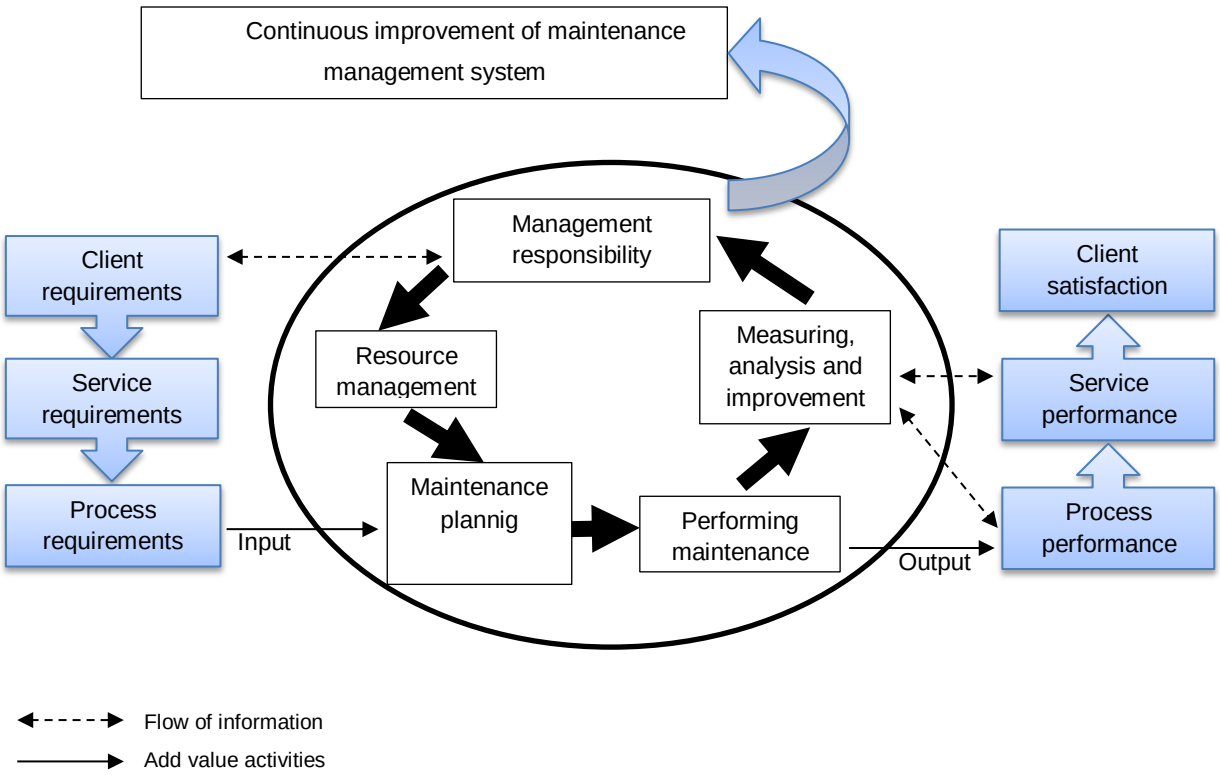

Figure 2.24 - Model of a maintenance management system process oriented [23]

As we can see in the figure 2.24, the middle circle is the five pillar of the maintenance organization. The system will bring the connection between the company and the client, adding a continuous improvement system.

This system is aligned with other systems, for example whit NP EN 9001:2008 - Sistemas de Gestão da Qualidade (Quality Management System), NP EN ISO 14001:2004 – Sistemas de Gestão Ambiental (Environmental Management System), among others.

To apply the system we have to follow the standard NP 4483:2009 – Guia para a implementação do Sistema de Gestão da Manutenção (Guide for the implementation of the maintenance management system). In this standard are the requirements that the company should follow. However, before the implementation the company must have the maintenance organization complete and operational. All five pillars working together effectively.

The procedure for implementing a service management can be executed in the following step:

1. The creation of a work team;
2. The audit diagnosis;
3. Development goals;
4. Preparation of the work plan;
5. Developing a timeframe;
6. Implementation of the implementation plan;
7. Verification;
8. Corrective action / continuous improvement.

This procedure based on PDCA cycle, when we achieved the step 8 we can return to step 3 or step 1, and restart the procedure.

Implementing and maintain a maintenance management system is the beginning of creation of an excellent service that intend to reach out the interest of the company and fulfilling the clients requirements.

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Chapter 3

Case of Study

This chapter intent to develop the detail of components of the maintenance management system and consequently the maintenance organization. Contemplating specific maintenance of heavy machines and best approach to the maintenance service.

The general concepts are outlined now the research will be on creating procedures and supports, complementing with appropriate decision models.

3.1. Maintenance organization Methodology

Performing the maintenance is the execution of the plans, the application of maintenance methods. Works like repair, lubrication, calibration, inspection, condition control. Is doing the job of maintenance service.

Maintenance is not little process in the company, is an essential process. Achieving excellence in maintenance allows, naturally, to reduce maintenance costs, but above all, the entire company achieve excellence.

All Supply Chain Programs require reliability and stability in production processes. If these processes are not meticulously executed, none of them will be worth. Remark that the center of a good maintenance is organization, for a great implementation program, execution and success of these.

In this work is proposed two different types of diagnostic audit:

1. Diagnostic audit for Good practices of maintenance;
2. Diagnostic audit for Maintenance Management System

3.1.1. Maintenance Management System and diagnostic audit

A Maintenance Management System (MMS) is designed to allow the company to demonstrate its ability to consistently provide a service that meets customer requirements, legal and regulatory requirements. Thereby increasing customer satisfaction through effective application of the system, including processes for continual improvement, based on customer requirements and regulatory requirements. Audits are a systematic and methodical way to verify that system requirements are adequate and/or disabilities is evident.

Audit consists of an initial diagnostic survey, independent, rigorous and documented with necessary data for the proper analysis and objective evaluation of compliance, according requirements as the benchmark chosen. This audit intends to remove information that will give a starting point for planning necessary for proper implementation adjustments of the MMS.

Diagnostic audit has as main objective to determine what is already and not within compliance with a chosen reference requirements: Identify potential improvement areas, check if already complies with the policies and objectives set by the organization and provide management information on the current organization status regarding future system implementation.

Work plan for a diagnostic audit is:

• Diagnosis audit plan preparation sent for organization approval;

• Use of labor required for registration during diagnosis audit, documents such as: checklists and supporting evidence;

• Performing diagnostic audit in accordance with the following steps:

- Opening meeting;

- Collection and verification of information;

- Preparation of audit findings for diagnosis;
- Preparation of audit report of the diagnosis;
- Closing meeting.

In preparation diagnostic audit, was elaborated a checklist based on the NP 4483: 2009 (Appendix I). Still another document that was designed to serve future situations, the audit report (Appendix II), was this paper which was presented at the closing meeting.

3.2. Study of organization and availability of heavy machines

This case of study will have simulation with some assumption for understanding how to organize maintenance in order to guarantee the maximum possible time of availability.

Heavy machine chosen for this study:

1. Excavator;
2. Forest Machine;
3. Wheel Loader.

As already written in this work this kindly of machinery work in extreme condition whit different operator, overload of workings hours and short intervals for maintenance. Is very important that during the production don't exist any breakdowns.

Every breakdown should be analyzed by methods, as per example: Cause Effect Analysis (CEA); Failure Mode Effect Analysis (FMEA) our Fault Tree Analysis (FTA). From these results it is possible to have elements to better organize maintenance [20].

That's why construction of the machines historic is crucial to organize maintenance in an appropriate way. Through these we can use analyses as such, Reliability studies: "failure rate (λ); Mean Time between Failures (MTBF); Mean Time To repairs (MTTR), Availability and Reliability Values" [20]. Use all this data to reduce time between repair, less breakdowns, use maintenance more effective and efficient.

When the breakdown happens, normally activities are compromised, this means delays in the project. This entails high costs, increasing production loss we have to add maintenance costs [31]. According to a study "61% breakdowns of machinery are in range of 7 to 10 hours of downtime" (for wheels Loaders) [20].

Also according to the author's study:

- "Mean time between failures for Wheel Loaders for engine, electrical, hydraulic, wheel assembly, propeller shaft, and axle assembly is high and hence more attention is required.
- Mean time to repair on Wheel Loaders is high with engine, transmission, differentials and axle drive components
- The engine, wheels, hydraulic and electrical of Wheel Loaders have the reliability values of 99.96% and less wherein the wheels have a value of 99.80% and less" [20].

For Forest Machine we can say that "the machine operator greatly affects the output of the

harvester. In recent work studies of single grip harvesters the difference between work outputs of experienced harvester operators has been as much as 40% or more" [32].

3.2.1. Maintenance of Excavator, Forest Machine and Wheel Loader

The first approach have to be executed by the operator, is essential that in the beginning of the project do inspection / examination and test of equipment. During the work day operator have four essential daily tasks:

1. **Prestart**: Operator should do a check according the check list of the machine. Was elaborated a checklist (Appendix III). Looking for lose bolts, leaks, any item damage, oil levels, grease points, etc.
2. **Warm it up**: Before start any work engine should run between 5 to 10 minutes, this allows the equipment archive the right pressures; systems approach the right temperatures to start the work. If during this preform operators hear any unusual noise must shutdown engine and check. And finally check breaks and test the movements of equipment coupled.
3. **While work**: Operator must maintain caution of equipment during operations, have to check constantly monitoring of the equipment performance. Any noise or strange changes appear should stop operation and check.
4. **Shut-down routine**: Park the machine on level ground, lower the work equipment properly and apply parking brake. The engine should work between three to five minutes before shutdown. Record the machine hours, prepare the machine for the next day (clean some dirt and/or debris, filling fuel tank).[33]

For recommended preventive maintenance normally the manual book contains, in Appendix IV there is a chart that exemplify how to organize maintenance by working hours, the task that have to be executed and time for them; for the three types of heavy machinery in study.

The main objective is to check the availability of the heavy machine (excavator, forest machine and wheel loaders). It was considered 90% of maintenance is preventive and the remaining 10% corrective maintenance. In order to maintain this balance is very important that operator do the four essential daily tasks. Therefore, below a diagram how the operator should proceed for check lists.

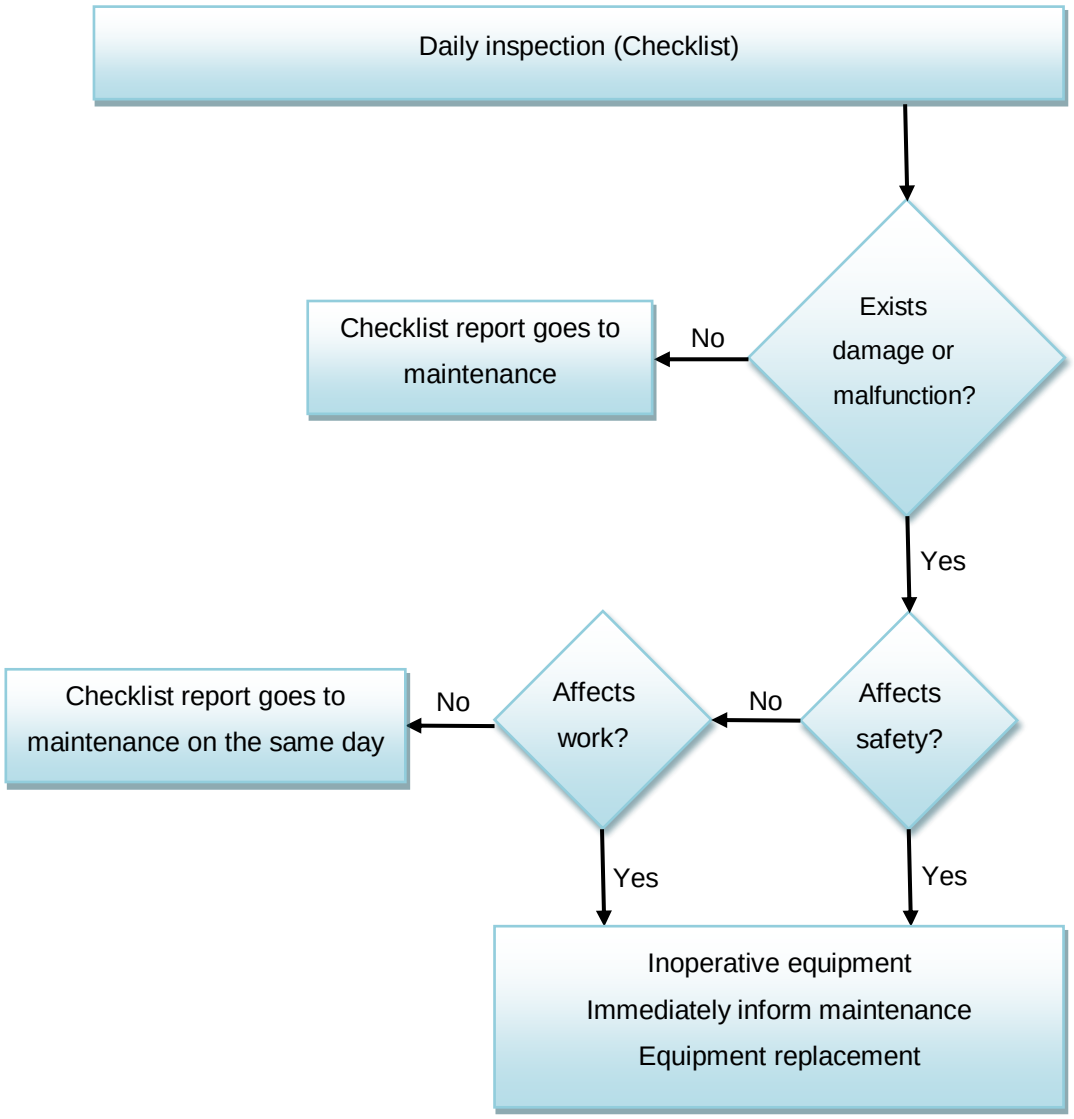

Figure 2.25 - Diagram how the operator should proceed for check lists

3.2.2. Key Performance Indicators for the case study

As already written in this paper, in this case of study, KPI's are indicators to measure maintenance performance. The indicators are used to assess improvement and efficiency and effectiveness, in order to improve maintenance performance.

In order to archive the machine availability we have to first check other indicators. Based in the working hours, number of stops for maintenance and time spend in the maintenance, it's possible to calculate:

- **λ** - Failure rate

Failure rate is defined as the variation in the expected number of breakdowns during elapsed time.

$$\lambda = \frac{Nr\ of\ failures}{Nr\ of\ working\ hours} \quad (1) \qquad [34]$$

- **MTBF** - Mean Time Between Failures

Mean time between failures is a value that represents when a failure may occur in a particular equipment, describes is reliability. The higher this index, the greater the reliability of the equipment and, consequently, the maintenance will be evaluated on efficiency issues. This indicator can help to define which equipment is the most fallible, in other words shows which ones needs more maintenance, or even needs to be replaced.

$$\mathrm{MTBF} = \frac{Nr\ working\ hours - Nr\ \ hours to\ repair\ the\ failure}{Nr\ of\ failures} \quad (2) \qquad [21]$$

- **MTTR** – Mean Time To Repair

Mean time to repair represents the average time required to troubleshoot and repair the equipment, returning him to is initial operating condition. The main goal is reduce MTTR, in order to happen is important to do preventive maintenance decrease the number of breakdowns and also reduce the time required for repair.

$$\mathrm{MTTR} = \frac{Total\ maintenance\ time}{Nr\ of\ repairs} \qquad (3) \qquad [21]$$

- **A** – Availability

Availability is the amount of time that the equipment is available to operate as scheduled. This value is the main goal of maintenance management.

$$A = \frac{MTBF}{MTBF - MTTR} \qquad (4) \qquad [21]$$

- **R** – Reliability

Realiability represents the probability that the device will have to perform a required function under conditions of use and for a specified period of time. Reliability tends to decline over time, while reliability increases over time

$$\mathrm{R} = e^{-\lambda \mathrm{t}} \quad (5) \qquad [21]$$

Calculation table with results presented in appendix V.

Chapter 4

Presentation and discussion of results

This chapter is describes some considerations taken into account in this report. Intends to analyse the results obtained in the calculation of indicators and present the conclusions of the study. Also points out the next step of this work.

4.1. Considerations, analysis of results and conclusions

The aim of this paper is the creation of a methodology to provide the organization with elements for an efficient system, which can be integrated with other management requirements, in order to help the organization to achieve the goals. To execute this work some knowledge of maintenance and maintenance organization is needed. This work centred the research on relevant concepts to create a maintenance system to the workshops specialised in heavy machines.

There is no doubt that maintenance is considered one of the most important and active areas in industrial activity and maintaining in these days demands new ways of thinking to keep the company competitive.

When we speak about maintenance the costs are always associated. Both are important issues and the goal is keep the two issues balanced having due regard to production standards so that quality and safety are maintained. The answer to this equilibrium problem is a well sustained maintenance organization. This organization is based on five pillars and in each one of them there are a number of items to define and organize.

The Maintenance Management System aims not only to organize the maintenance and to establish contact with customers. Therefore by applying the maintenance management system the question to organize the maintenance will be also resolved.

When a heavy machine has a breakdown the costs will rise exponentially. Not only the maintenance costs but also costs of the time that machine is not producing. That's why it is very important to prevent the breakdowns. Therefore the availability of these machines has to be high in order to maintain the machine in production. Taking into account the objective of optimization of costs, efficacy and availability of equipment, the chosen method and most appropriate to this study, was Reliability Centred Maintenance.

In this type of machines there are the checklist and maintenance manual with guidelines for maintenance, but there are no procedures for the machine operator. Therefore, for the three types of machines chosen were outlined: checklists, preventive maintenance / maintenance times and the procedure diagram to be followed by the operator when he is performing the checklist. Whit this methodology it's possible to systematize the maintenance policy and obtain a maintenance system that includes operators in the process. This methodology was designed to be integrated in the maintenance management system. These documents and procedures take into account various points of Portuguese Standard EN NP 4483:2009.

The results presented in Appendix V show that the application of methodology and considering the ratio of 90% preventive maintenance and 10% corrective maintenance machines have an average availability of 99,87%, 99,60% and 99,80%, each machine respectively. This is considered to be a good availability of equipment and meets the objective. We can conclude that the maintenance organization, based on the maintenance management system using this methodology, makes possible a good availability of the machine to be guaranteed.

4.2. Future investigation

In order to continue the development of this work it is necessary to apply and test the application of a maintenance management system. Choose and define economical indicator to check if results meet the objective of reducing costs in maintenance.

Also implement the outlined methodology, verify results and compare with the ones obtained in this report.

There is always possibility to improve the method and methodology presented, applying continuous improvement.

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Appendices

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Appendix I - Table of questions for a diagnostic audit

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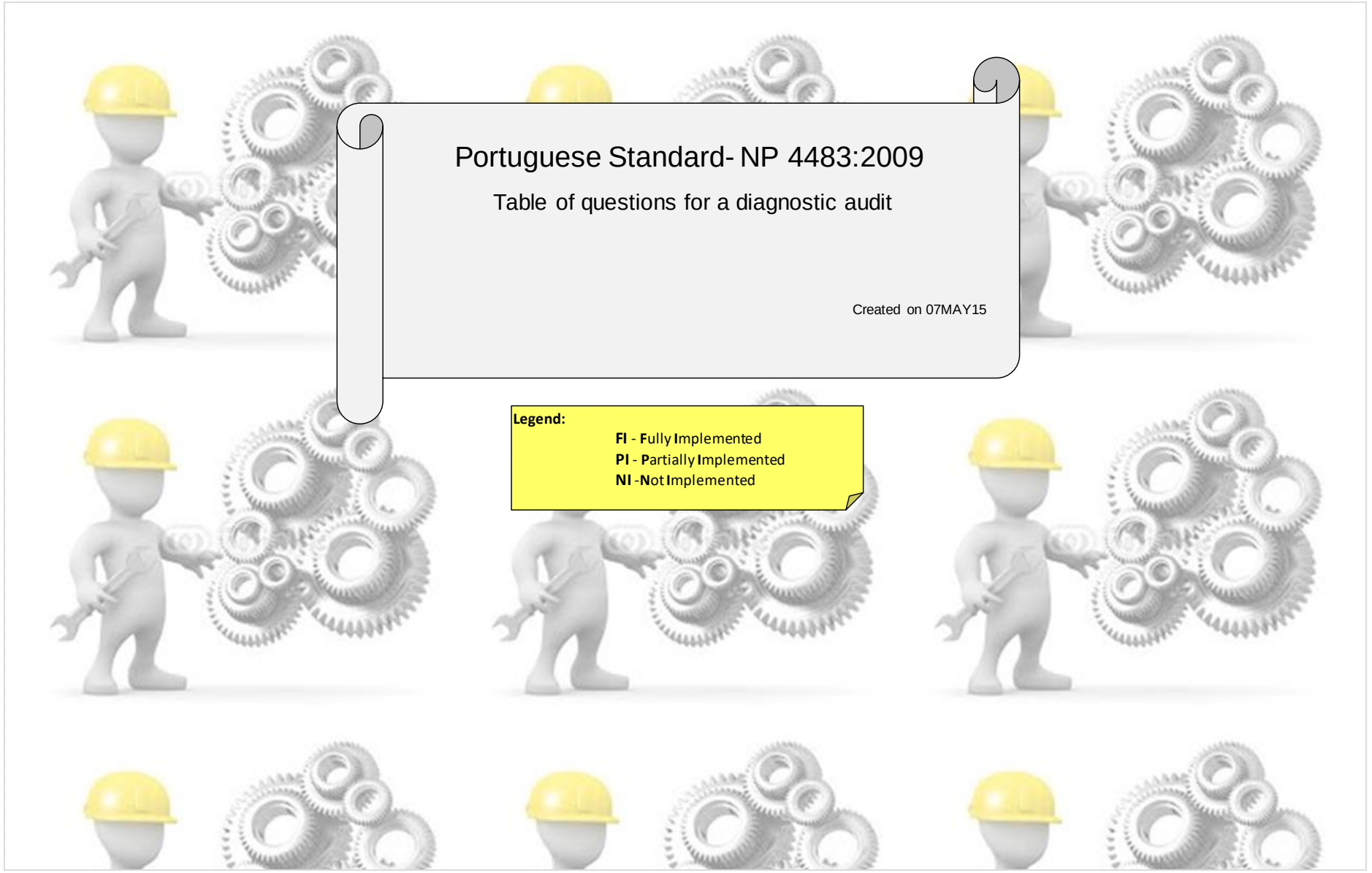

Portuguese Standard- NP 4483:2009

Table of questions for a diagnostic audit

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Legend:

FI - **F**ully **I**mplemented
PI - **P**artially **I**mplemented
NI -**N**ot **I**mplemented

4. Requirements

	EVIDENCE	FI	PI	NI	OBSERVATIONS
4.1 General requirements					
	Has the maintenance direction a defined maintenance strategy and establish, document, implement and maintain the maintenance management system and continually improve its effectiveness, according to the standard?				
	Should the organization :				
1	a) establish objectives and goals for the maintenance functions?				
2	b) establish processes that consider important to the maintenance system and their aplication?				
3	c) establish the sequence and interaction of this processes?				
4	d) establish criteria and methods needed to ensure the execution and control of this processes in an efficient way?				
5	e) assure the resources disponibility and information needed to suport the execution and supervision of this processes?				
6	f) supervise, measure (when applicable), and analise this processes?				

7	g) implement necessary actions to obtain the planned results and the continuos improvement of this processes?					
4.2 Documentation requirements						
	4.2.1 Generalities					
8	Maintenance policy exists? Have included the maintenance goals?					
9	The maintenance handbook exists?					
10	The procedures are documented? And the required records to?					
11	Exist documentation determined by the maintenance managenment to assure the planning, oprations control of the process in a efficient way?					
	4.2.2 Maintenance manual					
12	The maintenance direction establish and keep the maintenance handbook?					
13	In the handbook is included the scope of the maintenance management system, details and justification for any exclusions?					
14	Is included the documented procedures established for the maintenance management system, or related there to?					

15	Is included a description of the interaction between the processes of the maintenance management system?					
	4.2.3 Documentation control					
	Is documented the procedure to establish the control to:					
16	a) approval and suitability of the documents to their emission?					
17	b) review and/or update and revalidate documents?					
18	c) assure that the modification state of the corrent revision is identified?					
19	d) assure that relevant versions of applicable documents are available at points of use?					
20	e) assure that the documents are legible and easily identifiable?					
21	f) assure that the external source documents used by the maintenance direction as required for the planning and operation of the maintenance management system are identified and their distribution is controlled?					
22	g) and anticipate the improper use of obsolete documents, identify them conveniently if they remain active for any reason?					

	4.2.4 Records control				
23	There is a documented procedure to define the controls needed for identification, archive, protection, retrieval, retention and disposal of records?				

5. Management Responsibility

	EVIDENCE	FI	PI	NI	OBSERVATIONS
5.1	Management commitment				
	The top management is commited to:				
24	a)comunicate with the maintenance direction the importance to meet the clients requirements, regulatory requirements and regulations?				
25	b)establish a maintenance policy?				
26	c)assure the review by management?				
27	d)lead the review by management?				
28	e)assure resource availability?				
5.2	Maintenance policy				
29	Is suitable to the objective of the organization?				
30	Is included the commitment to accomplish the requirements and continuosly improve the efficacy of the maintenance management system?				
31	It provides a framework for establishing and reviewing the maintenance objectives?				

32	Is communicated and undertstood in the organization?					
33	Is review to maintain suitable?					
5.3	Planning					
	5.3.1 Maintenance Goals					
34	Are goals measurable and consistent in order to assure service requirements fulfillment?					
	5.3.2 Maintenance Management System Planning					
35	Top management should insure:					
	a)conducting 4.1 requirements and maintenance goals acomplishment?					
	b)is Maintenance Management System integrity held when changes are planned and implemented?					
5.4	Responsibility, authority and communication					
	5.4.1 Responsibility and authority					
36	Does top management assure that responsabilities and authorities are defined and communicated within the organization?					
	5.4.2 Management Representative					
	Does an elected management member have the authority and responsability that includes:					

37	a)assuring maintenance management systems necessary processes being established, implemented and held?					
38	b)reporting to top management maintenance management system improvement needs?					
39	c)assuring promotion awareness towards client requirements with management direction?					
	5.4.3 Internal Communication					
40	Does top management insure communication processes establishment appropriate within the organization to broadcast maintenance management system eficiency?					
5.5	Review by management					
	5.5.1 Generalities					
41	Does top management periodically review organization maintenence management system in order to be eficient, adequate and appropriate?					
	5.5.2 Necessary elements for the review					
	Do information elements include:					

42	a)auditon results?					
43	b)client feedback?					
44	c)management performance indicators review?					
45	d)preventive and corrective actions state?					
46	e)actions follow-up from previous management reviews?					
47	f)changes afecting maintenance management system?					
48	g)improvement recommendations?					
	5.5.3 Review Results					
	Do they include all actions and decisions relative to:					
49	a)maintenance management system and process eficiency improvement?					
50	b)service improvement towards client requirements?					
51	c)resources needs?					

6. Resource Management

	EVIDENCE	FI	PI	NI	OBSERVATIONS
6.1 Resources provision					
	Does maintenance direction use necessary resources adequately to:				
52	a)implement and preserve maintenence management system and continously improve it's eficiency?				
53	b)increase client satisfaction meeting his requirements?				
6.2 Human resources					
	6.2.1 Generalities				
54	Does personnel whose work affects quality have competences based on education, specialized qualification and adequate experience?				
	6.2.2 Competence, training and awareness				
	Does maintenance direction:				
55	a)determine necessary competences to the personnel whose work affects service quality?				
56	b)provide education or promote other actions that satisfy these needs?				
57	c)assure that necessary competences are acquired?				

58	d)assure personnel awareness of their activities relevance and importance as they help achieving organization goals?				
59	e)maintain appropriate registration of education, speacialized formation, qualification and experience (see 4.2.4)?				
	6.2.3 Qualification of maintenance staff				
60	Is the international Frame Reference guideline on personnel qualification used?				
61	Are the three qualification levels presented in CEN/TR 156282007 contemplated?				
6.3 Infrastructure					
	Does the infrastructure include:				
62	a)buildings workspace and associated facilities?				
63	b)adequate equipment and tools(hardware and software)?				
64	c)supporting services(transport, communication or information systems)				
6.4 Work environment					
65	Does the maintenance management determine and manage the working environment in order to obtain conformity with service requirements (see 3.1) ?				

7. Service realization

	EVIDENCE	FI	PI	NI	OBSERVATIONS
7.1 Planning the service execution					
	Does MD appropriately determine:				
66	a)service maintenance goals and requirements?				
67	b)needs to establish processes, documents and specific resources provision?				
68	c)required activities for verification ,validation, monitoring, inspection and rehearse specific to the service and his acceptance criteria?				
69	d)necessary registrations to provide evidence that realization processes and resulting service observe requirements?				
7.2 Processes carried out with the client					
	7.2.1 Determination of requirements related to the service				
	Does the MD determine:				
70	a)client specificated requirements?				
71	b)requirements not declared by the client but necessary to solicited or specified intended use, where known?				
72	c)ruled and normative requirements related to the service?				

73	d)any aditional requirements by them determined?				
	7.2.2 Review of the requirements related to the service				
	Does MD assure:				
74	a)service requirements definition?				
75	b)intervention requests changes requirements solved?				
76	c)have apptitude to meet defined requirements?				
	7.2.3 Communication with the client				
	Does maintenance direction establish and implement eficient communication towards:				
77	a)service information?				
78	b)client feedback, including client complaints?				
7.3	Design and development of the service				
	7.3.1 Planning the design and development of the service				
	During conception and development planning, MD does establish:				
79	a)steps?				
80	b)revisions, verifications and validations adequate to each step?				
81	c)responsabilities and authorities?				
	7.3.2 The data to design and development of the service				
	Does data include:				

82	a)functional and performance requirements?				
83	b)normative and ruled appliable requirements?				
84	c)where appliable, similar previous conceptions resulting information?				
85	d)other essential requirements for conception and development?				
	7.3.3 Results of the design and development of the service				
	Do results:				
86	a)fulfill design and development data requirements?				
87	b)provide adequate information in order to buy and/or supply the service?				
88	c)contain or refer service acceptence criteria?				
89	d)specify essential service features to preform in appropriate safety and ambience conditions?				
	7.3.4 Review, verification, validation and change control of the design and development of the service				
	According to planned provisions:				
90	a)do development and conception results fulfill requirements when evaluated?				

91	b)does resultant service fulfill requirements in specific application or in intended use (performance indicators analisis, complaints and unconformities)?				
92	c)are any problems identified and necessary actions taken?				
7.4 Purchase service					
	7.4.1 Process of the puschase service				
93	a)Does MD assure that hired service is according to specified purchase requirements?				
94	b)Does MD evaluate and select service providers based on their aptitude in serving according to requirements?				
	7.4.2 Specification of the purchase service				
	Does hired service specification describe, including when suitable:				
95	a)requirements for service approval, procedures, processes and equipments?				
96	b) personnel qualification requirements?				
97	c)Maintenance management system requirements?				
	7.4.3 Contracted service verification				

98	a) Does maintenance direction establish and implement inspection and other necessary actions to ensure that hired service fulfills purchase specified requirements?				
99	b)When proceeding to inspections on providers facilities does maintenance direction declare on purchase required checking provisions?				
7.5	Service Provision				
	7.5.1 Service Provision Control				
	Does MD carry out and plan service provision under controled conditions, including when appliable:				
100	a)information disponibility describing service features?				
101	b)work instructions disponibility, as necessary?				
102	c)appropriate equipment utilization?				
103	d)measurement and monitoring devices disponibility and use?				
104	e)measurement and monitoring implementation?				
105	f)receiving, approval and post reception activities implementation?				
	7.5.2 Service provision qualification procedures				

	When results canot be verified by monitoring or measurement and qualification ought demonstrate processes aptitude towards planned results, does MD establish:				
106	a)defined criteria for processes approval and review?				
107	b)equipment approval and personnel qualification?				
108	c)specific methods and procedures use?				
109	d)records requirements (see 4.2.4)?				
110	e)revalidation?				
	7.5.3 Identification and traceability				
111	Does MD maintain records in order to identify determined service provisions?				
112	Is MD able to identify a service conformity to their own monitoring and measurement requirements?				
	7.5.4 Equipment and materials preservation				
113	According to requirements does MD preserve materials and equipments by identifying, handling, packaging, storing and protecting?				
7.6 Monitoring and measuring devices control					
	To assure valid results is measurement equipment:				

114	a)calibrated or verified within specified intervals or before use, face to traceabble measuring standards and national or international measuring standards?				
115	b)adjusted or readjusted when necessary?				
116	c)be identified in order to determine calibration state?				
117	d)safeguarded from adjustments that may invalidate measurement results?				
118	e)protectected from damage and deterioration during handling, maintenance and storage?				

8. Measurement, analysis and improvement

	EVIDENCE	FI	PI	NI	OBSERVATIONS
8.1 General requirements					
	Does maintenance direction (MD) plan and implement monitoring, measurement,analisis and maintenance processes improvement to:				
119	a)demonstrate service requirements conformity?				
120	b)assure maintenance management system conformity?				
121	c)maintenance management system eficiency continuous improvement?				
8.2 Monitoring and measurement					
	8.2.1 Customer satisfaction				
122	Does MD monitor client´s perception towards their requirements fulfillement?				
	8.2.2 Internal audits				
	Does MD in programmed intervals determine if maintenance management system is:				
123	a)according to previously established (see 7.1), relative to Standard and maintenance management system organization requirements?				
124	b)is effectively implemented and held?				

	8.2.3 Monitoring and measurement of the procedures				
125	Do measurement and monitoring methods show maintenance processes programed results achievement?				
126	Does MD in methods definition consider monitoring and measurement type and extention towards their impact in service´s requirements conformity and maintenance management system eficiency?				
	8.2.4 Monitoring and measurement of the services				
127	Are service requirements acomplishments verified, by adequate steps during service execution in reaching programed results?				
128	Do records identify people who approved the service?				
129	Does service acception and execution not take course till planned provisions (see 7.1) have been satisfactorily completed, except when approved by relevant authority?				
8.3 Nonconforming service control					
	Are nonconformities controled and treated:				
130	a)taking actions to eliminate them when detected?				
131	b)authorizing their use, acceptation under a relevant authority permission?				

132	c)taking actions that prevent original use or application?				
133	d)after service conclusion on nonconformity detection, taking appropriate actions to her effect or potential effect?				
8.4 Data analysis					
	Does analysis provide information towards:				
134	a)client satisfaction (see 8.2.1)?				
135	b)performance indicators?				
136	c)conformity to service requirements(see 7.2.1)?				
137	d)characteristics and trends of service and processes, including preventive actions opportunity?				
138	e)service providers, equipment, materials and parts?				
8.5 Improvement					
	8.5.1 Continuous improvement				
139	Should maintenence direction continuously improve the management maintenence system eficiency through maintenance policy implementation like: maintenance goals, audit results, results review, preventive and corrective actions and management review?				
	8.5.2 Corrective actions				

	Is there a documented procedure defining requirements to:				
140	a)nonconformities review (including client complaints)?				
141	b)nonconformities causes determination?				
142	c)evaluating actions needs to assure nonconformities non repetition?				
143	d)determine and implement necessary actions?				
144	e)undertaken actions results record?				
	f) undertaken corrective actions review?				
	8.5.3 Preventive actions				
	Is there a documented procedure defining requirements to:				
145	a)determine potential nonconformities and their causes?				
146	b)evaluating actions needs to prevent nonconformities occurrence?				
147	c)determine and implement necessary actions?				
148	d)undertaken actions results record?				
149	e)undertaken corrective actions eficiency review?				

Appendix II - Audit Report

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AUDIT REPORT

ID DOC

REPORT Nº: __/_____

GENERAL INFORMATION

1.1. Identification of the audited entity:

1.2. Headquarters Address:

1.3. Audited site (s):

1.4. Scope and type of audit: Diagnostic audit (according to Portuguese Standard- NP 4483:2009)

1.5. Audit date: Date of previous audit:

1.6. Identification of the Audit Team:

1.7 **People contacted and their role:**

Identify the names and roles of the persons in attendance at the initial meeting (IM) and final meeting (FM) and the names and roles of the principal responsible persons contacted during the audit.

GENERAL ORIENTATIONS

For the Audit Team

The purpose of this audit is to evaluate if the entity gathers the necessary requirements to fulfill the requirements for the scope indicated in 1.4.

This report must be completed in strict compliance with its format and no change is permitted at this level.

The audit team should seek to use clear, succinct and objective language to describe all situations in all situations, activities or processes that may be classified as non-conformities and / or opportunities for improvement, and which have been identified during the sampling process in the audit.

The audit team should describe their findings (opportunities for improvement and non-conformities) on the corresponding page (s) of this report, numbering them and identifying in each of them the section of the applicable standard and explaining them to the entity. If possible, it should also indicate what corrective actions the entity auditee intends to take and their implementation deadlines.

Nonconformities should be classified, where applicable, in Minor (Ni), Major (Ma) or Critical (C).

A copy of this report, signed by the audit team and the person (s) responsible for the audited entity, shall be delivered to the audited entity. The audit team should put initial in all pages.

For the Audited Entity

This report describes the findings of the audit team during the course of this audit and is the result of a sampling, being the responsibility of the audited entity to evaluate them, as well as to identify any others that may have been detected existed ones and not detected, correlated or not with those indicated, and proceed to corrective or improvement measures with the aim of maintaining their system in accordance with the specified requirements.

Audit Team are obliged to the confidentiality, so all the information that they have had access to perform this audit will not be made available to others without the express authorization of the audited entity.

REPORT Nº: __/_____

SUMMARY OF THE AUDIT

Describe your conclusions and, when applicable, identify the relevant audited records / documents relating to each of the subjects below, which served as a basis for your evaluation and final recommendation

2.1.	**General conclusions - assessment of the level of implementation and effectiveness of the system:**
2.2.	**Changes in the entity: (eg at the level of organization, main activities and operations, relevant resources, etc.):**
2.3.	**Management responsibilities:**
2.4.	**Operational control of processes:**
2.5.	**Monitoring the performance of the objectives and results achieved:**
2.6	**Compliance with applicable legal requirements:**
2.7.	**Non-conformities, complaints, accidents and corrective / preventive actions:**
2.8.	**Internal audits:**
2.9.	**Review of management system (s):**

2.10.

Other comments: *(eg compliance with audit plan, unaudited areas / locations identification, continuous improvement process, strengths and areas for improvement, divergent opinions between the audit team and the audited entity, etc.)*

SUMMARY BY AUDITED SYSTEM

Identify audited processes / areas / activities by associating them with the respective scope of the audit.

Mark as appropriate: Y – audited; N – not audited; NA – not applicable.

Processes / areas / activities audited	NP 4483:2009

FOLLOW-UP OF CORRECTIVE ACTIONS OF THE PREVIOUS AUDIT

NC nº	Effective?		Description of the current situation (if "no")
	Yes	No	
	☐	☐	
	☐	☐	
	☐	☐	
	☐	☐	

OPPORTUNITIES FOR IMPROVEMENT (OI)

The findings described here are considered as an **opportunity for improvement** - a finding that does not call into question the fulfillment of a specified requirement (in standard, statutory or regulatory, or subscribed by the organization), but whose resolution can contribute to the improvement of the system or its performance.

OI nº	Standart	Clause nº	Description of the improvement opportunity
1			
2			
3			
4			
5			

NON-CONFORMITIES (NC)

The findings described here are considered to be **non-compliant** with the applicable standard according to the Minor (Mi), Major (Ma) or Critical (C) non-compliance classification.

A entidade auditada deve proceder à sua correcção e às acções correctivas adequadas, dentro do prazo estabelecido, da data da sua efectiva implementação, enviando as evidências que lhe forem solicitadas.

The audited entity must proceed to correction of corrective actions, in the established period, of the date of is effective implementation, sending the evidences that are requested.

NC nº	Standart(s)	Clause nº	Description of non-conformity
1 (_)			
2(_)			
3(_)			
4(_)			
5(_)			
6(_)			

VALIDATION OF THE REPORT BY THE AUDITING TEAM

Duration of the audit:

Report Date:		
Identification of the Audit Team:	Nº half days 2	Signature (s):

ACCEPTANCE OF THE REPORT BY THE AUDITED COMPANY

"I declare that I have taken note of the contents of this report, of which I have been provided with a copy. I undertake to create a corrective action plan, when required, within the timeframe set forth in FR.

Date:	
Identification of the person (s) of the audited entity:	Signature (s):

Appendix III – CheckList’s

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Safety & Maintenance Checklist - Excavators

Operator/Inspector_____ Date_____ Time_____

Serial Number_____ Machine Hours_____

1. FROM THE GROUND

1.1	Bucket, GET		Excessive Wear Or Damage, Cracks		
1.2	Bucket Cylinder & Linkage		Excessive Wear, Damage, Leaks		
1.3	Stick		Damage, Cracks		
1.4	Boom, Cylinders		Wear, Damage, Leaks		
1.5	Underneath Of Machine		Final Drive Leaks, Damage		
1.6	Carbody		Cracks, Damage		
1.7	Undercarriage		Wear, Damage, Tension		
1.8	Steps And Handholds		Condition And Cleanliness		
1.9	Batteries & Hold Downs		Cleanliness, Loose Bolts & Nuts		
1.10	Air Filter		Restriction Indicator		
1.11	Windshield Wipers & Washers		Wear, Damage, Fluid Level		
1.12	Engine Coolant		Fluid Level		
1.13	Radiator		Fin Blockage, Leaks		
1.14	Hydraulic Oil Tank		Fluid Level, Damage, Leaks		
1.15	Fuel Tank		Fuel Level, Damage, Leaks		
1.16	Fire Extinguisher		Charge, Damage		
1.17	Lights		Damage		
1.18	Mirrors		Damage, Adjust for best visibility		
1.19	Overall Machine		Loose Or Missing Nuts & Bolts, Loose Guards, Cleanliness		
1.20	Fuel Water Separator		Drain		

2. ENGINE COMPARTMENT

2.1	Swing gear oil level		Fluid Level		
2.3	Engine Oil		Fluid Level		
2.4	All Hoses		Cracks, Wear Spots, Leaks		
2.5	All Belts		Tightness, Wear, Cracks		
2.6	Overall Engine Compartment		Trash Or Dirt Buildup, Leaks		

3. INSIDE THE CAB

3.1	Seat		Adjustment		
3.2	Seat Belt & Mounting		Damage, Wear, Adjustment		
3.3	Indicators and Gauges		Check, Test		
3.4	Horn, backup alarm, lights		Proper Function		
3.5	Overall Cab Interior		Cleanliness		

4. OBSERVATIONS

*Based in checklists of CATERPILLAR [34]

Safety & Maintenance Checklist – Forest Machines

Operator/Inspector_____ Date_____ Time_____

Serial Number_____ Machine Hours_____

1. FROM THE GROUND

1.1	Grapple		Excessive Wear or Damage, Leaks		
1.2	Boom and Stick		Excessive Wear or Damage		
1.3	Implement Cylinders		Excessive Wear, Damage, Leaks		
1.4	Underneath of Machine		Final Drive Leaks, Damage		
1.5	Overall Undercarriage		Packing/Debris buildup		
1.6	Idlers & Rollers		Leaks, Damage, Wear		
1.7	Drive Sprockets		Wear, Damage, Loose Bolts		
1.8	Track Assembly		Tightness, Damage, Bent or Broken Shoes		
1.9	Swing Bearing		Damage, Loose or Missing Bolts		
1.10	Underneath of Machine		Final Drive Leaks, Damage		
1.11	Steps and Handholds		Condition and Cleanliness		
1.12	Overall Machine		Loose of Missing Nuts & Bolts, Loose Guards, Cleanliness		

2. ENGINE COMPARTMENT

2.1	Engine Oil		Fluid Level		
2.2	Swing Drives		Fluid Level		
2.3	Engine Coolant		Fluid Level		
2.4	Air Filter		Restriction Indicator		
2.5	Radiator		Fin Blockage, Leaks		
2.6	All Hoses		Cracks, Wear Spots, Leaks		
2.7	All Belts		Tightness, Wear, Cracks		
2.8	Overall Engine Compartment		Trash or Dirt Buildup, Leaks		

3. ON THE MACHINE, OUTSIDE THE CAB

3.1	Fuel Tank		Fuel Level, Damage, Leaks		
3.2	Hydraulic Oil Tank		Fluid Level, Damage, Leaks		
3.3	Fire Extinguisher		Charge, Damage		
3.4	Windshields Wipers & Washers		Wear, Damage, Fluid Level		
3.5	Batteries & Hold Downs		Cleanliness, Loose Bolts & Nuts		

4. INSIDE THE CAB

4.1	Falling Object Guard		Damage		
4.2	Seat		Adjustment		
4.3	Seat Belt & Mounting		Damage, Wear, Adjustment		
4.5	Horn, Backup Alarm, Lights		Proper Function		
4.6	Overall Cab Interior		Cleanliness		

5. OBSERVATIONS

*Based in checklists of CATERPILLAR [35]

Safety & Maintenance Checklist – Wheel Loaders

Operator/Inspector_____ Date_____ Time_____

Serial Number_____ Machine Hours_____

1. FROM THE GROUND

1.1	Tires, Wheels, Lug Nuts, Stem Caps		Inflation, Leaks, Damage, Wear		
1.2	Bucket Cutting Edge, Moldboard		Excessive wear, Damage		
1.3	Bucket Lift and Tilt Cylinders, Lines, Hoses		Excessive wear, Damage, Leaks		
1.4	Loader Frame, Arms		Excessive wear, Damage		
1.5	Underneath Machine		Leaks, Damage		
1.6	Transmission, Transfer Case		Leaks		
1.7	Steps and Handholds		Condition, Cleanliness		
1.8	Fuel Tank		Fuel Level, Damage, Leaks		
1.9	Differential and Final Drive Oil		Fluid Level		
1.10	Air Tank (if equipped w/ air brakes)		Drain Moisture		
1.11	Axles – Final Drives, Differentials, Brakes, Duo-cone Seals		Leaks, Damage, Wear		
1.12	Hydraulic Tank		Fluid Level, Damage, Leaks		
1.13	Transmission Oil		Fluid Level		
1.14	Lights, Front and Rear		Function, Damage to Lens, Housing, or Wiring		
1.15	Battery Compartment		Cleanliness, Loose Nuts & Bolts		

2. ENGINE COMPARTMENT

2.1	Engine Oil		Fluid Level		
2.2	Engine Coolant		Fluid Level		
2.3	Radiator		Debris, Damage, Leaks		
2.4	All Hoses		Cracks, Wear Spots, Leaks		
2.5	Fuel Filters / Water Separator		Leaks / Drain Water (if equipped)		
2.6	All Belts		Tension, Wear, Cracks		
2.7	Air Filter		Restriction Indicator		
2.8	Overall Engine Compartment		Trash or Dirt Buildup, Leaks		

3. ON THE MACHINE, OUTSIDE THE CAB

3.1	Handholds		Condition and Cleanliness		
3.2	ROPS		Damage, Loose Mounting Bolts		
3.3	Fire Extinguisher/System		Charge, Damage		
3.4	Windshield, Windows		Broken Glass, Cleanliness		
3.5	Windshield Wipers / Washers		Wear, Damage / Fluid Level		
3.6	Doors		Open properly, broken glass		

4. INSIDE THE CAB

4.1	Seat		Adjustment-Height, Weight, Able to Reach Pedals		
4.2	Seat Belt & Mounting		Damage, Wear, Adjustment, Age		
4.3	Horn, Backup Alarm, Lights		Proper Function		
4.4	Mirrors		Damage, Adjust for Best Visibility		
4.5	Cab Air Filter		Dirt, Dust		
4.6	Gauges, Indicators, Switches, Controls		Damage, function		
4.7	Overall Cab Interior		Cleanliness		

5. OBSERVATIONS

*Based in checklists of CATERPILLAR [36]

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Appendix IV – Recommended Preventive Maintenance

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EXCAVATORS

EVERY X TIME	TASKS	MAINTENANCE TIME (hours)
10 HOURS OR DAILY	○ Check the coolant level and top up ○ Check the oil level in the oil pan and top up ○ Check the fuel level and top up ○ Check the oil level in the hydraulic tank and top up ○ Check the air filter clogging indicator ○ Check the water separator ○ Check the wiring systems ○ Check the functionality of the horn	0,25
50 HOURS	○ Check machine visually ○ Change oil in the hydraulic tank and clean the filter	0,17 0.45
500 HOURS	○ Lubrication ○ Change engine oil and the engine oil filter cartridge ○ Change fuel filter cartridge ○ Check oil level in the final reduction gears ○ Check and clean the fins of the radiator and of the exchanger ○ Check and adjusting the fan belt tension ○ Drain the hydraulic oil tank (only for machines in which synthetic biodegradable oil type hees is used)	1,17 0,25
1000 HOURS	○ Change hydraulic filter element ○ Change oil in the final reduction gears ○ Check and adjust the engine valve clearance	1,00
2000 HOURS	○ Change oil in the hydraulic tank and clean the filter ○ Change coolant ○ Check alternator and the starter	1,00
2 YEARS OR 4000 HOURS	○ Change Fuel pipe (fuel tank - water separator) ○ Change Fuel pipe (water separator – fuel pump) ○ Change Fuel pipe (fuel pump - fuel filter) ○ Change Fuel pipe (fuel filter - injection pump) ○ Change Fuel pipe (fuel filter – fuel tank) ○ Change Fuel return pipe (fuel filter - injection pump) ○ Change Fuel return pipe (between the nozzles) ○ Change Fuel return pipe (nozzles – injection pump) ○ Change Fuel return cap ○ Change Hydraulic pipe (main pump suction) ○ Change Hydraulic pipe (main pump delivery) ○ Hydraulic pipe (boom cylinder) ○ Change Hydraulic pipe (boom cylinder) ○ Change Hydraulic pipe (bucket cylinder) ○ Change Hydraulic pipe (swing cylinder)	3,75
3 YEARS	○ Change seat belts	0,33
AS REQUIRED	○ Clean the machine ○ Change, clean the air filter cartridge ○ Check battery charge level ○ Clean the water separator filter ○ Drain the fuel tank ○ Check and adjust steel track tension ○ Check the rubber tracks ○ Check and adjust the rubber track tension ○ Change the rubber tracks ○ Bleed the hydraulic system	0,35 0,33 0,17 0,25 0,17 0,25 0,08 0,25 0,35 0,17

Note: Task at blue are executed only once

*Based in operation and maintenance Manual [37]

FOREST MACHINE

EVERY X TIME	TASKS	MAINTENANCE TIME (hours)
10 HOURS OR DAILY	○ Check hydraulic oil level ○ Check engine oil level ○ Check boom structures visually	0,17
50 HOURS OR WEEKLY	○ Check machine visually ○ Check the cooler cleanness ○ Grease middle joint ○ Check and grease cabin Rotation and levelling system ○ Check slew housing oil level ○ Grease the boom	0,25
250 HOURS	○ Check high/low gear oil level ○ Check bogie casing oil quality and level ○ Check tyre pressures ○ Check the door switch ○ Check cabin fresh-air filters ○ Check extension boom clearances	1,00
500 HOURS	○ Change engine oil and oil filter ○ Replace fuel filters ○ Check the drive belt wear ○ Check crankcase vent tube ○ Check air intake system ○ Check cooling system ○ Drain water deposited in boom base ○ Check electrolyte level of batteries	1,17
1000 HOURS	○ Change hydraulic oil ○ Replace hydraulic tank oil filters ○ Replace hydraulic tank breather ○ Bleed hydraulic tank ○ Replace drive pump filter ○ Grease the driveshafts ○ Grease bogie slew bearings ○ Check wheel rims and fastening bolts ○ Check frame brake fastening screws ○ Check air conditioner ○ Change cabin fresh-air filters ○ Clean rotator magnetic plug ○ Tighten rotator bottom screws	2,25
2000 HOURS	○ Check valve clearance ○ Change coolant ○ Check vibration damper ○ Change high/low gear oil ○ Change differential oil ○ Change bogie casing oil ○ Change hub gear oil ○ Check axle fastening bolt torques ○ Change boom slew housing oil	2,35
AS REQUIRED	○ Clean the machine ○ Replace air filter elements ○ Check engine coolant level ○ Replace coolant filter ○ Drain fuel filters ○ Replace drive belt ○ Replace dryer-filter-receiver ○ Check secondary exit ○ Check cabin stairs	0,35 0,25 0,08 0,25 0,17 0,35 0,35 0,03 0,03

	○ Check drive brake oil level		0,08	
	○ Check brake cylinders		0,03	
	○ Change brake pedal circuit oil		0,50	
	○ Adjust brake cylinders		0,25	
	○ Adjust rotator link dampening		0,25	
	○ Inspect chain shot guard		0,08	

*Based in forest machine operator training programe [38]

WHEEL LOADER

EVERY X TIME	TASKS	MAINTENANCE TIME (hours)
10 HOURS OR DAILY	○ Check engine oil level ○ Check coolant level ○ Check hydraulic oil level ○ Check fuel level, Drain the water and the sediment from the fuel pre-filter ○ Check the operation of the lights and gauges ○ Check tire pressure and wear ○ Check transmission oil level ○ Check the lubrication at all lubrication points, apply grease to them according to the Machine Lubricating ○ Check oil level of the brake booster ○ Check transmission control system, make adjustment if necessary ○ Check and tight the retaining nuts of the steering wheel ○ Walk around and visually inspect all the systems weather there are abnormal or leakage ○ Visually inspect engine fan and drive belt ○ Apply grease to every driveshaft according ○ to the Machine Lubricating Figure attached on the machine ○ Tight all driveshaft connecting bolts	0,25
50 HOURS	○ Check the clearance between the parking brake shoe and brake drum, make adjustment if necessary ○ Check the tightening torque of rims connecting bolts ○ Initially replace the engine oil and oil filter	0,75
250 HOURS	○ Initially replace the powertrain filter and the oil for the transmission, torque converter and radiator ○ Initially replace the hydraulic tank return element (upper element on the oil tank) ○ Initially replace pilot hydraulic system oil filter element ○ Keep the battery post clean and apply Vaseline on it to prevent acid fog from corrosion ○ Check the tightening torque of rims connecting bolts ○ Change engine oil and oil filter ○ Clean radiator fins ○ Clean filling screen of the fuel tank ○ Clean filling screen of the engine oil tank ○ Check the tightening torque of the engine and transmission mounting bolts ○ Check work tool, front and rear frames, stress welding seams, and retaining bolts for cracks or loose ○ Check the oil level of front and rear axle ○ Check the engine air inlet system ○ Check the engine drive belt, air conditioning compressor belt for tension and damage ○ Check the operating capacity of service brake and parking brake and clearance between the parking brake shoe and brake drum ○ Change engine oil and oil filter ○ Change fuel pre-filter	0,75 2,50

500 HOURS	○ Clean pilot hydraulic system oil filter element ○ Check the retaining bolts of frame hinge pin for loose ○ Check oil level of the brake booster ○ Tighten connecting bolts between frame and front, rear axle ○ Clean the screen of the air booster breather ○ Change fuel filter ○ Change oil tank breather element ○ Change air filter element	1,75
1000 HOURS	○ Adjust engine valve lash ○ Check the bearings of the engine tension pulley and the fan shaft bearing case ○ Fasten all the retaining bolts of the battery, clean the top of the battery ○ Clean fuel tank ○ Clean transmission, torque converter breather ○ Replace the oil for the transmission, torque converter and radiator ○ Replace transmission suction screen and return screen ○ Replace the hydraulic tank return element (upper element on the oil tank) ○ Replace the lubricating oil of the axles ○ Initially replace pilot hydraulic system oil filter element	3,00
2000 HOURS	○ Check the engine shock absorber ○ Check the operation of service brake system lines and parking brake system. If necessary, remove and inspect the abrasion of disc, and replace brake lines ○ Check the flexibility of steering system, replace steering lines if necessary ○ Check the generator, starting motor, clean up the turbocharger ○ Clean the seals and springs of brake booster, replace the brake oil, check the sensitivity of each brake ○ Check the sealing of distribution valve and power cylinder by measuring the cylinder natural subsidence ○ Change oil tank breather (filling screen) ○ Change fuel tank breather (filling screen) ○ Change coolant and coolant filter, Clean cooling system Replace the coolant every two years if the service hours do not occur first ○ Replace hydraulic oil, clean hydraulic tank and check the suction pipe	6,30

Note: Task at blue are executed only once

*Based in operation and maintenance Manual [39]

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Appendix V – Calculation table

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EXCAVATOR

Working hours	Nr for PM	Nr breakdowns	time for PM (hour)	time for CM (hour)	λ (breakdowns/hour)	MTBF (horas)	MTTR (horas)	MTTR (PM)	MTTR (CM)	A (%)	R
500	11	1	3,57	0,17	0,0020	499,83	0,31	0,32	0,17	99,94	
1000	12	0	4,12		0,0000		0,34	0,34			
1500	11	1	3,12	0,33	0,0020	499,67	0,29	0,28	0,33	99,94	
2000	13	0	5,12		0,0000		0,39	0,39			0,000045
2500	11	2	3,12	1,17	0,0040	249,42	0,33	0,28	0,59	99,87	
3000	12	1	4,12	0,5	0,0020	499,50	0,36	0,34	0,50	99,93	
3500	11	3	3,12	2,5	0,0060	165,83	0,40	0,28	0,83	99,76	
4000	14	2	8,87	0,42	0,0040	249,79	0,58	0,63	0,21	99,77	
	90%	10%			0,0025	360,67				99,87	

FOREST MACHINE

Working hours	Nr for PM	Nr breakdowns	time for PM (hour)	time for CM (hour)	λ (breakdowns/hour)	MTBF (horas)	MTTR (horas)	MTTR (PM)	MTTR (CM)	A (%)	R
500	13	2	6,67	1	0,004	249,50	0,51	0,51	0,50	99,80	
1000	14	0	8,92	0	0,000		0,64	0,64			
1500	13	0	6,67	0	0,000		0,51	0,51			
2000	15	1	11,27	1	0,002	499,00	0,77	0,75	1,00	99,85	0,000006
2500	13	3	6,67	1,75	0,006	166,08	0,53	0,51	0,58	99,68	
3000	14	0	8,92	0	0,000		0,64	0,64			
3500	13	0	6,67	0	0,000		0,51	0,51			
4000	14	6	11,27	4	0,012	82,67	0,76	0,81	0,67	99,08	
	90%	10%			0,003	249,31				99,60	

WHEEL LOADER

Working hours	Nr for PM	Nr breakdowns	time for PM (hour)	time for CM (hour)	λ (breakdowns/hour)	MTBF (horas)	MTTR (horas)	MTTR (PM)	MTTR (CM)	A (%)	R
500	4	1	8,25	2,00	0,0020	498,00	2,05	2,06	2,00	99,59	0,049787
1000	4	0	9,75				2,44	2,44			
1500	3	1	6,75	0,33	0,0020	1499,67	1,77	2,25	0,33	99,88	
2000	5	0	16,05				3,21	3,21			
2500	3	1	6,75	0,25	0,0020	2499,75	1,75	2,25	0,25	99,93	
3000	4	0	9,75				2,44	2,44			
3500	3	0	6,75	0,75			2,50	2,25			
4000	5	0	16,05				3,21	3,21			
	91%	9%			0,0008	1499,14				99,80	