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Francisco Ferreira Integrative Maintenance Strategy

Universidade do Minho
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DECLARAÇÃO

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RESUMO

A globalização catapultou a competição entre empresas para um nível mundial, onde estas lutam pela sobrevivência quer com os seus concorrentes, quer entre diversas unidades de uma mesma empresa espalhada pelo planeta. Com cada vez mais opções à escolha, os clientes como dominantes nesta competição, exigem cada vez mais qualidade e rapidez às organizações que pretenderem liderar. A responsabilidade pelo alcance destes requisitos já não está apenas consignada à gestão da produção, sendo cada vez mais partilhada com a gestão da manutenção, dado o alargado impacto que esta função tem nos objectivos estratégicos das empresas tais como a produtividade, a qualidade, a segurança e a protecção ambiental. Inúmeras estratégias de manutenção, bem como considerações sobre as mesmas continuam a constituir um desafio para os gestores, estratégias essas que ainda não são de fácil compreensão, são de difícil implementação e que necessitam primeiramente da mudança de algumas linhas de pensamento ainda existentes. Este trabalho apresenta um modelo de manutenção com foco numa abordagem proativa, como se requer, mas tendo como base estratégias bem conhecidas e amplamente implementadas como são o caso da manutenção correctiva e da manutenção preventiva regular. A partir do melhor das experiências destas duas abordagens, é construído um modelo de manutenção que integra os objetivos estratégicos de toda a empresa no planeamento das atividades desta função.

PALAVRAS-CHAVE

Gestão da Manutenção, Manutenção integrada e integrativa, Estratégias de Manutenção, Manutenção Condicionada, Engenharia Concorrente

ABSTRACT

The globalization of business brought a world-wide scenario of competition, putting companies in a real fight for survival against their competitors which includes different company's plants and the same organization's plant as well. As customers are the dominant player with a wide range of options form their demands, quality and speed are the requirements for the winners. These demands are no longer exclusively manufacturing responsibility and are being shared with the maintenance management as this function's activity has a wide impact in the major business strategic goals of productivity, quality, safety and environmental protection. Countless maintenance, strategies and considerations, are still challenging maintenance managers, most of those policies hard to understand, difficult to create the basic condition for implementation and mind-set changes needing. The present case study presents a maintenance model focusing on a proactive maintenance approach, having as basis the most well-known and widely implemented maintenance strategies such as failure-based maintenance and use-based maintenance schemes. Starting from the best of these two approach's experiences, an integrative maintenance model is built where all the strategic goals of company are taken into account for this function's activity planning.

KEYWORDS

Maintenance Management, Integrative Maintenance, Maintenance Strategies, Condition-based Maintenance, Concurrent Engineering

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Lista de Abreviaturas, Siglas e Acrónimos

CM - Corrective Maintenance

PM – Preventive Maintenance

DOM – Design-Out Maintenance

FBM – Failure Based Maintenance

UBM – Use Based Maintenance

CBM – Condition Based Maintenance

PDM - Predictive Maintenance

RCM - Reliability-Centred Maintenance

TPM - Total Productive Maintenance

RCA - Root-cause analysis

OEE - Overall Equipment Effectiveness

MTBF – Mean Time Between Failure

MTTR – Mean Time To Repair

CMMS - Computerized Maintenance Management Systems

FMEA – Failure Modes and Effects Analysis

iCBM – Integrative Condition-Based Maintenance

1. INTRODUCTION

1.1 Background

Nowadays the survival of a company is made not only by its products attractiveness or concept innovation rate, but also by the speed of response for delivery of products with good quality at the lower possible cost.

To produce on time, with quality and fastness is not anymore a task only under the responsibility of the Production Management. Within this thought, the role of departments as the Quality or Engineering, functions like Procurement among others, are highly significant. In fact the Engineering department, responsible for the company equipment technological level as well as the one that undertake the mission of keeping its performing state, is easily recognized as fundamental for the success of the overall business. Therefore some companies have already realized the importance of a serious partnership with the Maintenance function, due to its deep impact and involvement in the business goals (Waeyenbergh & Pintelon, 2002).

In the process industries, maintenance costs can account to as much as 40% of the operational budget, thus becoming a potential savings source (Eti, Ogaji, & Probert, 2006). Seen in the past as a “necessary evil” (AHC Tsang, 1995), Maintenance, in its modern concept, is a “profit generating business element” with high impact in costs and quality, safety and health, environment and may also be a motivation element for the technicians and machine operators (Sharma, Yadava, & Deshmukh, 2011).

Once established an adequate maintenance strategy, supported by the adequate means (spares, tools and equipment), regular training with the aim of keeping up-to-date the technological knowledge of the team, the boundary conditions for a motivated and successful maintenance team will be as well established.

Regular breakdown occurrences, due to poorly maintained equipment, have a direct impact in the delay of the delivery of goods. This effect is even worst when the equipment is, for this reason, already seen as critical to operate, leading to a demotivation and lower performance of its operator.

In addition, an inadequate maintenance plan concerning the production facilities or equipment may be the hidden root cause of non-conformity production or scrap (Swanson, 2001) as some effects like unforeseen slower/faster movements; non-conforming pressure/temperature, etc., may have critical impact in the product. The worst cases happen when these effects are not detectable or visible.

Regular failures mean significant investments in human efforts and spares to restore the equipment to its operational state and might have a critical impact in the company operating budget. Energy saving has also a big impact in the company profitability, as it is to reduce or eliminate any type of waste (Eti et al., 2006). The cost of compressed air for instance, makes it really worth to influence maintenance routines. The machine itself will have a short lifetime when a correct maintenance plan is not followed (Swanson, 2001).

Finally, as technology and product characteristics are evolving very quickly, this brought to the Maintenance Management the limelight of a complex mission: to be the best in class (Marquez & Gupta, 2006).

Maintenance is therefore a set of activities with the purpose of keeping or to restore an asset to a state where it can perform its function as it was designed to (Komonen, 2002). The relevance of the Maintenance function has a high influence to meet the production targets at an optimal cost, with quality, preserving safety with the respect to environmental protection and laws (Muchiri, Pintelon, Gelders, & Martin, 2011).

1.2 Problem formulation

How to implement an integrated and balanced maintenance strategy in a successful company, taking advantage of the existing resources and its experience and know-how, in order to improve the results of this function activities and their impact in the overall company objectives? Are the Concurrent Engineering principles also valid in Maintenance Management?

The discussion will be how to find the appropriate approach for a maintenance strategy taking into account all the challenges that this function faces in the current days: to improve the equipment availability, output and quality, at a lower cost and high level of safety and environment harmony.

1.3 Purpose of the study

The thesis work is focused in the development of a concurrent approach which introduces the latest maintenance management strategies, monitoring its results and influencing people and their way of thinking in order to give a quality step in the maintenance response to its daily business challenges.

1.4 Time frame plan for the study

The execution of the thesis work followed the planning and time frame below:

Step 1 – Objectives definition / project planning.

Step 2 – Research and literature review with critical analysis of maintenance concepts and management bibliography sources

Step 3 – Analysis and diagnosis of the company state of the art based on data collecting from reports and observations.

Step 4 – Proposals study and presentation

Step 5 – Proposals implementation plan and execution

Step 6 – Results analysis

Step 7 – Preparation of the dissertation

The Gantt diagram of the project is shown in the fig. 1:

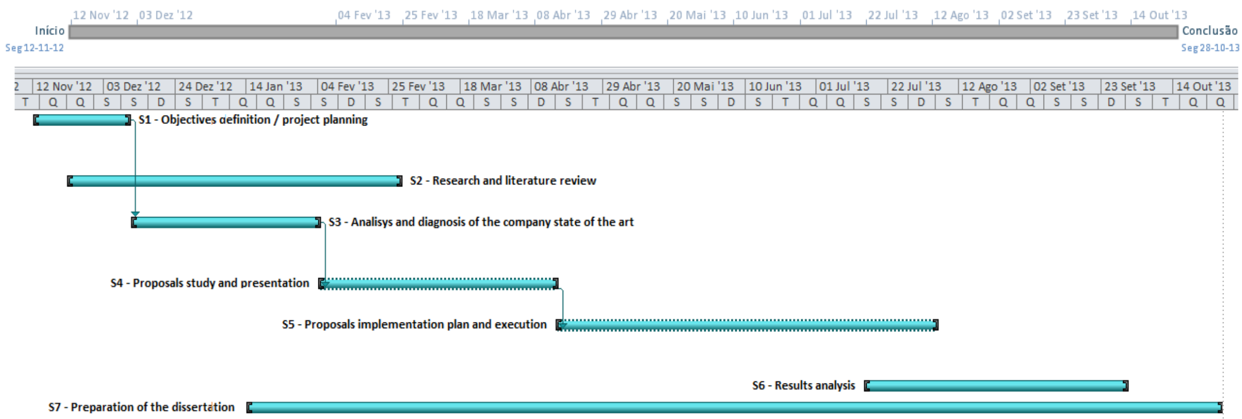


Figure 1: Gantt diagram

1.5 Research methodology

The conducting research method work was an Action-research in a process industry.

The research philosophy was based on a Pragmatism philosophy with an Inductive approach. Data was collected using the existing key performance indicators reported in the existing CMMS (Computerized Maintenance Management Systems); several knowledge sources were studied in order to achieve the best answer to the research question and goals.

The Experiment strategy was also used to test the proposal's impact and effects as well as to validate the presented model.

Data (mainly quantitative but also qualitative) collecting and analysis, as well as measurements were foreseen with a mix method strategy, in a transverse horizon time.

2. LITERATURE REVIEW

2.1 Maintenance definition

According to the European Committee for Standardization (CEN/TC 319), *the function of Maintenance incorporates the combination of all the technical, administrative and managerial actions during the life cycle of an item intended to keep it in, or restore it to a state in which it can perform the required function*.

British Standard 3811 defines maintenance as *the combination of all technical and associated administrative actions intended to retain an item in or restore it to, a state in which os can perform its required function*.

Hence, the maintenance characterization includes not only the repair or overhauling operation as it is the widely concept associated to this function, but also includes the management aspects and requirements of this activity.

Some authors define Maintenance as an activity, in which repairs are executed at certain intervals, with the aim of extending the useful life of a machine or equipment, of to improve its availability and to retain it in a proper condition (Swanson, 2001). In a more ambitious concept, Maintenance is also presented as the activities required to keep a facility in "as built" condition and therefore continuing to have its original productive capacity (Sharma et al., 2011).

There is a general consensus in the main goals of the Maintenance function (Komonen, 2002):

- to optimise the production equipment's availability and
- to keep is operational costs as lower as possible.

However, Maintenance definition comprises, in the current descriptions, factors as safety care, health and environment objectives, maintenance costs control and cost of lost production monitoring (Sharma et al., 2011).

There is a common understanding of the increasing importance in the role of Maintenance in the pursue of important goals as the quality improvement of products, fast response to market, environment policies commitment and health and safety protection (Moya, 2004).

Maintenance should care about the components in a way they fulfil their functions. This mission depends of a wide range of actors such as the designers, the constructors the operators, as well as the mostly known responsible, the maintainers (Eti et al., 2006).

The Industrial Maintenance is defined as a strategic business task mainly engaged to ensure the proper functioning of the Production's utilities. Is taken as a service linked to new management models, to the technological progress and to the need of reducing costs, which mission is no longer limited to repair the failures but also to anticipate and avoid the malfunctions not only presentially, but also in remote way (Rachidi, Talbi, & Khatory, 2013).

2.2 Evolutionary perspective of Maintenance

Since the industrial revolution two centuries ago, much has changed in engineering, even though the great changes have occurred in the last fifty years. However, the main maintenance challenges of that time are similar to those facing maintenance management today (Guide, 1996).

The industrial revolution's new manufacturing process come up with the replacement of hands production methods by machines. Machinery was quite robust and it is still likely to have old equipment performing nowadays as they were made to, even though it can't achieve today's requirements of flexibility and speed.

Until the end of the Second World War, labour and capital costs were not comparable as today, thus meaning that downtime and repeated maintenance actions didn't require special attention by the management. These conditions led to a run-to-failure approach, with focus on repairing when it was broken, at the lower possible cost.

Table 1: Historically perspective of the maintenance mind-set

Historically	Today
to fix what is broken	to keep equipment running
focus is on operation	focus is on uptime, safety and environment, quality and service
support function	business driven
added cost activity	profit generating business element
negative impact to Production	high influence to meet Production targets
necessary evil	strategic function

Thus, maintenance has long played a corrective assignment with the single objective to reduce the downtime of the machines, as shown in the table 1. This corrective approach, fig. 2, resulting in the short term issues failed to solve problems such as de wear-out and the unavoidable degradation of the equipment's parts (Rachidi et al., 2013).

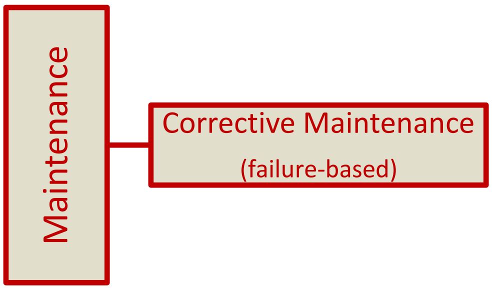


Figure 2: Failure-based approach strategy

After the Second World War, the industry rebuilding, especially in Japan and Germany, brought a much more competitive market, as more and more mechanisation and automation start to make part of the production process, bringing also higher speeds and the awareness for the waiting times as a waste to be eliminated. Uptime started to be a measured and common concept. Thus, failures got focus in order to be reduced or eliminated, by means of a new maintenance paradigm: the preventive maintenance.

The failure occurrence becomes no longer compatible with the companies' strategic goals and needs. This need of to anticipating malfunctions was the drive to a protective maintenance including actions and interventions on the equipment to replace certain parts in a degradation trail, to lubricate and to clean in a regular schedule in order to limit and control wear (Rachidi et al., 2013).

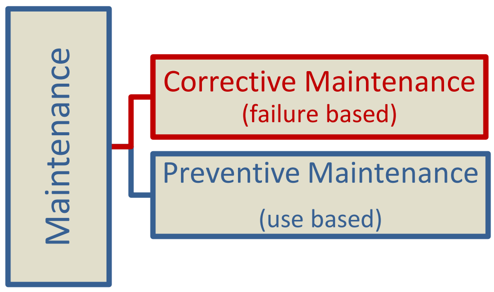


Figure 3: Corrective and Preventive maintenance approach

In spite of having now its importance recognized, maintenance was by then the so called necessary evil of the industry (AHC Tsang, 1995).

The activity of the preventive maintenance was carried out in a regular basis, according the prescribed periods of time or number of operations, allowing to avoid failures and to increase the uptime of the production equipment, although at the cost of a significant increase in maintenance charges (Rachidi et al., 2013).

However, to remain competitive in the market, companies had to rethink and improve their own strategies and management policies (Muchiri et al., 2011), even though they were of a proven success in the past.

In the current days, the Maintenance challenges are more and more to keep the equipment running by means of failure avoidance through high efficient preventive routines focusing in a positive contribution to the company's overall goals including costs reduction as strategy to improve the business profit margins (Eti et al., 2006).

Hence, a new mind-set has made changes in the maintenance mission: to avoid failures and improve the equipment's performance, change parts only in the last possible moment before being broken. This only become possible due to technological evolution, allied to the use of predictive and forecasting techniques, such as vibration monitoring, inspection routines, among others (Rachidi et al., 2013).

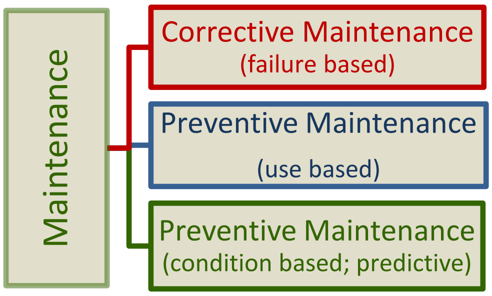


Figure 4: A proactive approach of maintenance

2.3 Maintenance Management

The globalisation of business brought a world-wide scenario of competition, putting companies in a real fight for survival against their competitors but not only, also within the same company, the plants have to compete with their partners from other regions or countries. As customers are the dominant player with a wide range of options from their demands, quality and speed are the requirements for the winners. Everything has to be fast in the manufacturing stream: raw material supply has to be fast, production has to be fast, and thereby, maintenance has to be very fast. This pushed toward the total quality management methods focus, to a daily technological challenges facing and to continuous concerns regarding the environment, health and safety (Waeyenbergh & Pintelon, 2004).

During the last decades, companies have focused on continuous improvement strategies, bringing to their production systems a set of just-in-time methods, a lean manufacturing environment, permitting the massively production in a customised and effective way, forcing the reduction of buffers, and putting efforts in the waste and scrap elimination. This search for total quality and especially the focus in the reduction of costs, added to an increasingly complexity in the automation of the manufacturing processes, has been converting maintenance in a strategic function of the organizations (Rachidi et al., 2013).

These changes has been transferring a high pressure to maintenance, mostly because a disturbance in the production flows may quickly become costly, due to the absence of "pillows" to absorb the impact of variations like downtimes or defect production (Popovic, Vasic, Rakicevic, & Vorotovic, 2012).

Maintenance is also in the literature shown as encapsulated process in the enterprise system, depicted in the figure 5 as an input-output model, illustrating the impact of the maintenance performance in the availability of production facilities, the volume, quality and cost of production, as well as safety of the operation (A Tsang, 2002).

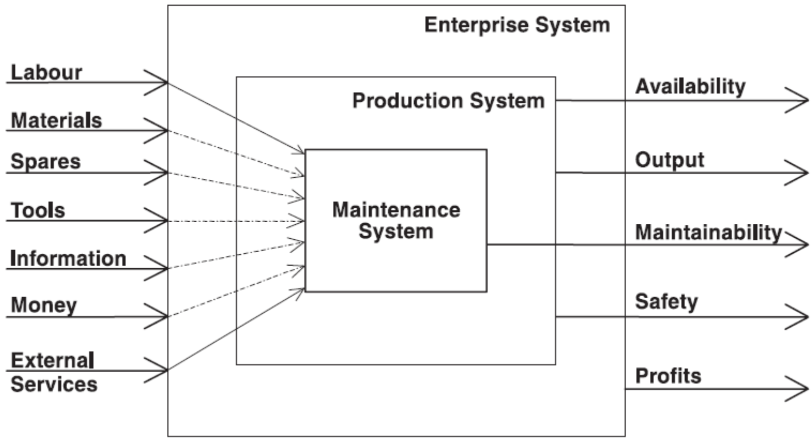


Figure 5: Visser maintenance model

The economic and political challenges of the last two decades have also contributed to reverse organizational cultures in order to reduce costs and energy expenditures in the organizations. To have a maximized return out of the manufacturing system, it is obvious that a high system availability is required (Waeyenbergh & Pintelon, 2004). This claims for a general rethinking in the light of maintenance management as this function may account a huge percentage of a company operational budget (Eti et al., 2006). Some authors identify companies in which the amount of money spent on maintenance can be as large as its net income. The chemical industry, known as the world's best performer, presents maintenance annually costs between 1,8-2,0% of the current replacement of the plant; however, in worst cases this percentage may arise above 5% (Waeyenbergh & Pintelon, 2004).

Therefore, business leaders progressively realised the strategic importance of the maintenance function in their organizations, as it has significant investments in the company's facilities, being so a necessary expense (Eti et al., 2006). Maintenance Management become to the limelight of overall business management, demanded by the stakeholders. Maintenance policies, traditionally centred on short term issues, have to change towards the consideration of longer terms goals like sustainability and strategy. In one word: reliability.

In this way, the requisites of the maintenance management (MM) are continuously increasing and so there is the need of regularly to revise the MM activity, which has to determine the maintenance objectives, priorities strategies and responsibilities, and implement them through the maintenance plan, control and supervision with the special focus on the financial aspects of the company (Marquez & Gupta, 2006). Moreover to keep the track of the plant availability in a stable and increasing way, it is mandatory that the maintenance concept is kept up to date and continuously developed (Waeyenbergh & Pintelon, 2004) and adapted to the new tendencies of the market and to the technology evolution. Tsang (1998) presents a process for managing maintenance performance from the strategic perspective (figure 6). Performance measures that are linked with the adopted strategy of the maintenance function must be tracked (A Tsang, 2002).

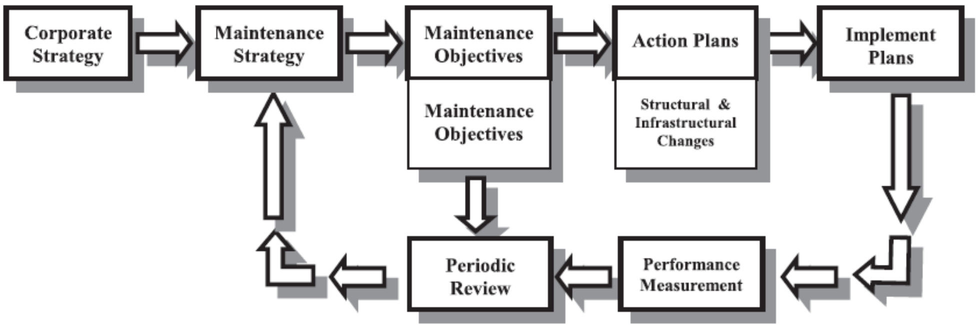


Figure 6: Tsang diagram for a strategic maintenance performance management process

At the present time, businesses are requiring innovation in the paradigms of the maintenance outdated behaviour: organizations should be changing from a repair-focused to a reliability-focused philosophy. The mission of changing mind-sets is doubtless the hardest one, which has to be undertaken originally by the management. Management has to set goals which provide the feeling of the business ownership for all within the organization, a real team group feeling. One for another, passion to win, freedom to act and trust, are values to be deployed within all the organization, combined with each goal and directly linked to the needs of those working in the organization in order to achieve the success of that organization. The reward is a problematic topic, however necessary. These rewards must be aligned with the success of the company's strategic goals and might be both, financial and non-financial: the most successful organizations combine a blend of the two (Eti et al., 2006).

The best practices in maintenance management aim to enable the company to achieve advantage over its competitors and should include (Eti et al., 2006):

- Preventive Maintenance as strategy to reduce the amount of reactive maintenance;

- Inventory and Procurement so set a focus on providing the adequate parts avoiding large stocks investments as well as the availability of the spare parts on time;
- Work flows and control knowledge, to define work-orders procedures and the clear-cut approval for each maintenance process;
- Computerized Maintenance Management Systems to support the maintenance activities management and all its activity tracking and reporting;
- Technical and personal training to ensure that all the maintainers have the necessary technical skills to understand and execute their jobs, and to provide them with the ability to wisely communicate within the team and with other departments and last but not least, to add to all the maintenance players the extremely needed ability to work as a team;
- Manufacturing (Production department) integration, highly linked with the implementation of TPM methodologies, each operator should receive at least basic maintenance training;
- Predictive Maintenance, with the focus on investigating and integration of technology (sensors, etc.), that allow to solve or to investigate chronic problems. This also includes inspections among other tasks, and all data has to be integrated into the CMMS;
- Reliability-centred maintenance as strategy to improve the knowledge and care about each equipment to be maintenance added to the focus on the maintenance activity's cost reduction;
- Financial optimization consisting in a statistical technique that combines all the relevant data about equipment, such as downtime, maintenance, lost efficiency and poor-quality or end-product costs in order to create a decision-making model to support a more cost-effective maintenance plan for each equipment;
- Continuous improvement as generic thought of the organization, looking for the "little things" that can improve the company's competitiveness.

The critical and success factors for a sustainable maintenance management have to include a technical and technological background with management skills, and flexibility to respond on time to the maintenance department challenges (Ruiz, Kamsu-Foguem, & Noyes, 2013).

The industrial maintenance management is currently highly influenced by the organizational culture, the technological evolution, by the growing of outsourcing availability and by the market and information technology (IT).

The maintenance best practices rely on the change of a paradigm, from a reactive behaviour to proactive manner of actuating in all the aspects of the function: from the planning of each intervention till the costs control of the overall activity. According to this scenario, companies are searching the maintenance best practices in order to set and adequate maintenance strategy which permit to achieve its goals of effectiveness and profitability.

However there is absence of maintenance management outlines, such that could be useful to improve the understanding of the underlying dimensions of maintenance, and that could explain the effects of preventive maintenance and integrating maintenance into manufacturing (Jonsson, 2000).

Moreover, the lack of operational preventive methodologies, the composition of a wide variety of maintenance activities for which is not easy to find procedures and effective information support systems, the high diversification of the problems and difficulties faced by the maintainers, the lack of the organizational and manufacturing processes knowledge, the lack of historical data, the lack of time for the execution of the required analysis tasks, the lack of top management support, the fear of production disturbs, the highly automation of the machines as well as the diversity of the technology of the overall plant machinery are some of the reasons behind the complexity of the maintenance (Marquez & Gupta, 2006). Therefore, a maintenance policy decision diagram might have a complex aspect as shown in the figure 7 (Waeyenbergh & Pintelon, 2004):

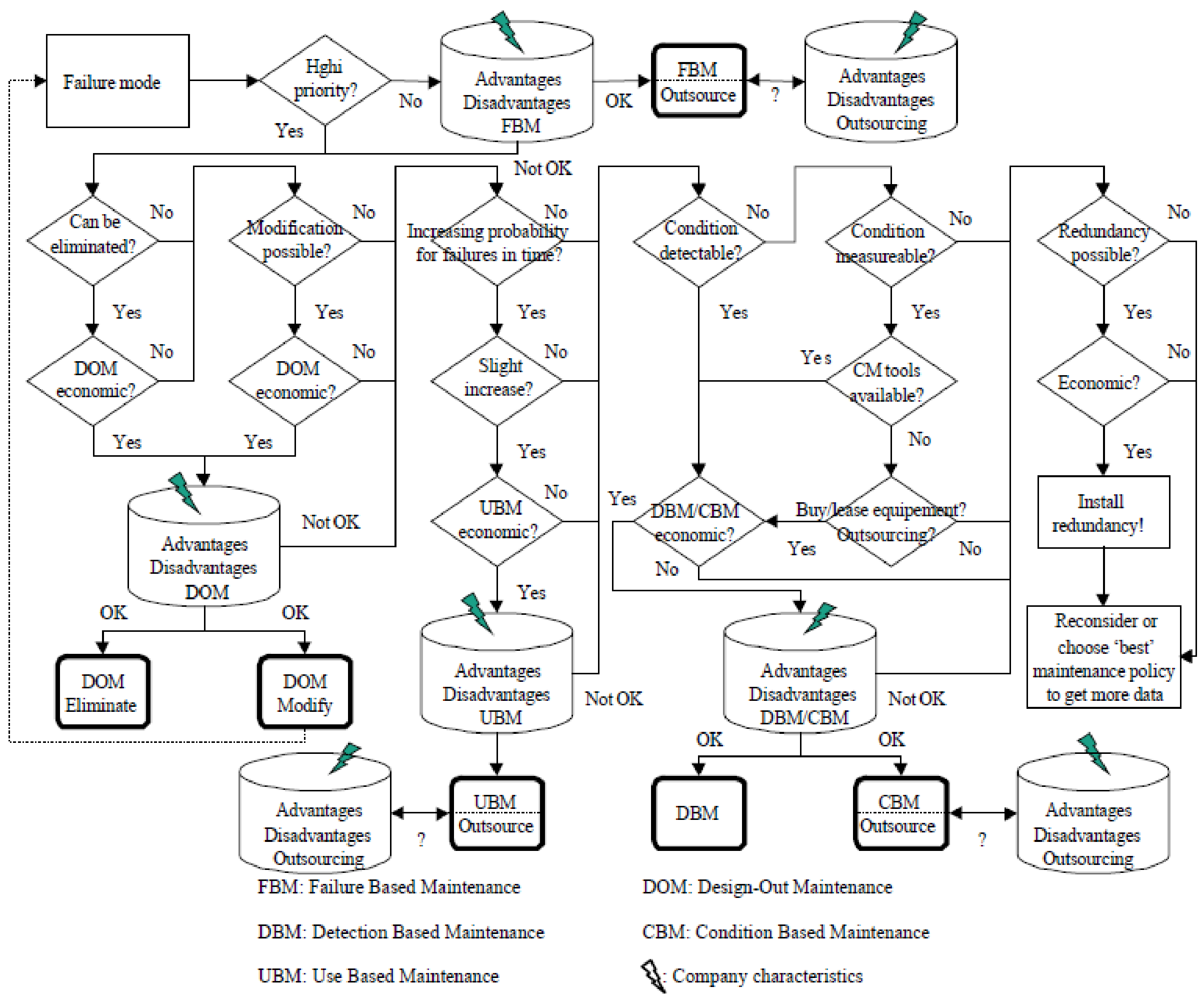


Figure 7: A Waeyenberg & Pintelon maintenance policy diagram

The innumerable considerations, data, policies, methods and tools affect the execution of maintenance. An alignment of the maintenance management with three levels of business activities – strategic, tactical and operational – is suggested in the literature (Marquez & Gupta, 2006).

In the strategic level of management, i.e., the goal is to transform business priorities into maintenance priorities, by means of an establishment of critical targets in the operations exercise.

Tactical decisions will determined the adequate assignment of resources to accomplish the maintenance plan. Within this tactical level, decisions regarding the planning and scheduling of the maintenance tasks should be taken according the overall maintenance strategy and guidelines.

By the other hand, at the operational level, maintenance tasks had to be assured by skilled personnel able supported on the correct procedures, and reported in the information system. These three action level are described in the diagram of the figure 8 (Marquez & Gupta, 2006):

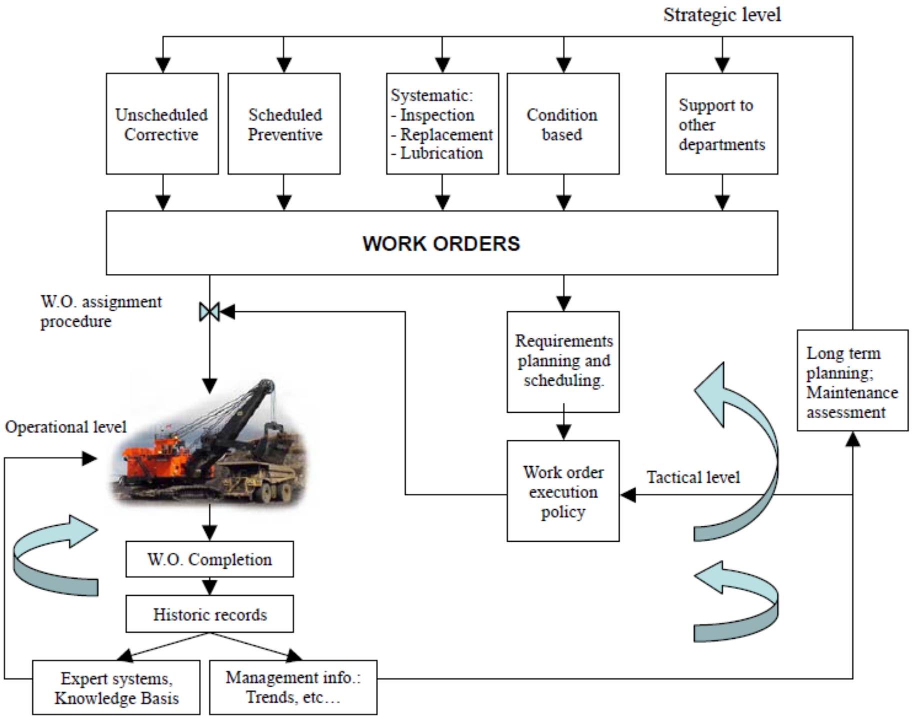


Figure 8: A Marquez and Gupta maintenance process diagram

This maintenance management approach is also present in the literature, according Maintenance organization modelling (MOM), which describes the maintenance organizations function at three major levels: at the organizational level (functional and structural relationships), at the process level (work activities planning) and job player level (individual worker) (Sharma et al., 2011).

2.4 Maintenance Strategies

Most companies nowadays have in their maintenance function, two main strategies: failure based maintenance (FBM) and used base maintenance (UBM). These appear to be the two most consensual management strategies in maintenance as, by the first one is given the continuous support to the production needs of "fire-fighting" downtimes due unpredictable malfunctions or breakdowns, and by the second one is established a strategy of avoidance of catastrophic failures which could seriously compromise production's capability.

However these two strategies are more and more not sufficient to achieve the overall goals of the company as they might have interesting level of effectiveness but both have serious efficiency losses: the usage of the resources in a FBM team has a huge variety and is often difficult to find the adequate number of elements as the number of breakdowns may have a wide range of occurrences; moreover, FBM may also disrupt production goals with unpredictable downtimes of the equipment. For the other hand, UBM is usually based on an old-fashioned premise of components replacement or overhaul by a fixed-time or number of operations cycles. This is seldom justifiable as less than 20% of all components fail within the usually recommended periods. In addition, both excessive frequency or under maintenance will decrease the production equipment availability (Eti et al., 2006).

There are three steps in the development of a Maintenance strategy (Eti et al., 2006), such as:

- to shape a plan of every specific requirement of each component;
- to acquire the adequate resources in order to execute the maintenance activities in a effective way (skilled personnel, spares and tool);
- to rollout the strategy supported in adequate systems needed to the effective management of the resources.

Additionally this plan has to have clear objectives, as to increase the equipment's uptime at least cost. Only a proactive profit-focused approach will slim the gap between the ideal costs and the desired costs. (Eti et al., 2006)

Maintenance most known categories are the Corrective Maintenance (CM) and the Preventive Maintenance (PM). Some authors distinguish the Predictive Maintenance from the Preventive Maintenance considering this one as a third category (Sharma et al., 2011).

Within this two major maintenance categories (CM and PM), five basic strategies are known (Waeyenbergh & Pintelon, 2004):

Failure Based Maintenance (FBM) – within the CM category this strategy uses a run-to-failure approach as maintenance approach of an asset according with production impact/significance criteria, costs analysis or repair quickness;

The failure-based maintenance (FBM) approach is planned in the sense that the team is built with the aim of ensuring that production's disruptions will have fast and effective answer, this meaning the congregation of high skilled personnel with the adequate tools and diagnosis means. However its action is reactive. The ignition of the action is the failure, being the typical activities of this approach, emergency actions such as repair, remedial and other unpredicted maintenance. Is often possible to happen the so-called deferred maintenance or temporary repairs, in a way to give back the equipment to its function as soon as possible, transferring the final and permanent repair for a more convenient time in future, maybe during a preventive maintenance period. Studies in the past show that the failure-based maintenance costs up to three times more than any other proactive approach (Jonsson, 2000). The reasons behind this fact are due to the repair itself costs added to the costs of an unplanned disruption of production, of a possible reduction of the equipment lifetime, or possible issues with health and safety of the operators as well as possible impact to the environment.

However, this strategy may be, in some cases, the most appropriate policy, for example in case of purely random breakdowns and low breakdown costs.

Design-Out Maintenance (DOM) – to change or influence the equipment design taking into account its performance improvement and/or maintenance tasks obstacles;

This strategy deals with refining the maintainability and reliability of the equipment in the design phase or by later physical modifications. To integrate with success the maintenance experiences in the design process it is highly essential to create tools and communication channels for the feedback of data to purchasing and machine constructors and the use of cross-functional design teams.

Use-Based Maintenance (UBM) – to schedule a set of regular maintenance task for a machine based on time of use, number of operation cycles executed, etc.;

This preventive policy is carried out at predetermined intervals or corresponding to prescribed criteria and is intended to reduce the probability of failure or the performance degradation of an item. It aims to reduce the breakdown occurrences by replacing and maintaining components after a specified number of cycles or time of usage. The main goal of this approach is to lower the equipment's downtime rate due to breakdown. Use-based maintenance interventions are for this reason, able to reduce the unpredictable cost of the failure. However, it represents constant costs an downtimes for its activity as the ignition for the repair or replacement are simply time or number of cycles and not the state of the component (Pintelon & Gelders, 1992).

Condition-Based Maintenance (CBM) – Performed when one or several signs observed show that a failure is coming up;

This approach concerns the preventive maintenance actions initiated as a result of knowledge of the changed condition of any particular equipment or machine part from routine or continuous monitoring (Jonsson, 2000). The root causes of potential failures have to be identified since the key characteristics of fundamental physical processes change from an initial value to a terminal value before failure occurs. The motivation for this approach comes from the fact that many companies reorganizes its processes, and emphasizes quality and flexibility capabilities to greater extent than before, which results in the need for early detection of potential disruptions in a way that the failure could be avoided as well as the maintenance activity costs could be reduced.

Visual inspection by the operator, well as the usage of five human senses by operators and maintainers are fundamental techniques to be considered within the range of this activity. Other techniques are also known as being the key for this approach, if considered that CBM includes the Detection Based Maintenance (DBM) approach, as described in the next point.

Detection Based Maintenance (DBM) – Strategy very closed to the previous one, but with special focus on the detection and the detection devices or equipment (sensors, etc.);

Several techniques such as vibration and other process parameters monitoring, thermography and tribology are used in this approach, so there is an high effort – and sometimes difficulty – in identifying the adequate parameters and detections means for each equipment.

2.5 Concurrent Engineering and Maintenance strategies

Concurrent Engineering in literature is related quite only to a product design process. It is considered to be the set of factors associated with the life cycle of the product during the design phase, including product functionality, manufacturing, assembly, testing, maintenance, reliability, cost and quality (Abdalla, 1999). The essence of Concurrent Engineering is not only the concurrency of the actions but also the supportive effort from all the involved teams, which leads to improving profitability and competitiveness.

Usually the objectives of Concurrent Engineering are defined to be the improvement of quality, to reduce manufacturing costs, or improve reliability of a product. Three main goals of Concurrent Engineering can be defined as (1) getting lower product costs throughout the total life cycle, (2) to achieve better product quality, (3) all of this in a short time-to-market (Willaert, de Graaf, & Minderhoud, 1998).

In literature the association of the concept of Concurrent Engineering to maintenance refers only to the work of changing and influencing the product design in order to improve the maintainability of that product (Abdalla, 1999). However, the three objectives above mentioned are similarly transposed to the design of the maintenance service.

The concurrency of functions in a company may lead to undesired results, even when applying widely successfully tested management methodologies. The overall equipment effectiveness (OEE) can easily decrease as a result of the implementation of just-in-time, lean manufacturing and total-quality management methodology (TQM) in an ineffective way. The closest relationship between the actions of these methodologies and the maintenance activities create conflicts and opposite results that the desired ones whether these strategies are not conveniently combined (Boyer & McDermott, 1999). Thus is highly desired that the strategies TQM and lean are widely assumed in a combined and uniformed way by the management of the company (Eti et al., 2006).

The integration of these two functions, Maintenance and Manufacturing (or Production), is inherent in the TPM methodology, where operators and maintainers are required to work together as a team in order to reduce waste and downtime rate and improve product-quality and the equipment effectiveness (Eti et al., 2006).

The level of integration is upgraded when it comes to the reliability-centred maintenance (RCM) process. This comprises to define the specific requirements of a physical component in order to ensure its performance in the way it is expected. However this purpose must be achieved combining with two objectives: to determine maintenance requirements and then to make sure that they are met as cheaply as possible (Eti et al., 2006).

The concept of an integrate maintenance activity involves the use of a wide range of skills, not available in single dedicated strategies work groups as a FBM, UBM or DOM group. This requires the construction of a small multi-disciplinary team (Jonsson, 2000).

Integration of maintenance into manufacturing is seen as driving toward a maintenance that is no more apart from the manufacturing challenges of mass customization, waste reduction, costs optimization and quality improvement. Therefore there were developed concepts of “hard integration” and “soft integration” variables in the process of integration of maintenance into manufacturing (Jonsson, 2000):

- The “hard” concepts, deals with the integration supported by technology, like computers, sensors, and other similar physical devices. This integration is essential for the predictive approach, where the aim is to monitor “online” the physical process which may signal the risk of a failure;
- By the other hand, “soft” integration includes human and work organizational combination as a key factor. Employees are empowered to make decisions, to build relationships and to take the

> needed steps to improve the performance within the guidelines defined by management. The central idea is to create an atmosphere for the efficient flow of information and continuous improvement by highlighting integration, prevention and empowerment.

Integration also means the personnel empowerment in a decentralized authority environment. Research in operations strategy has clearly shown that “learning organizations” with these characteristics are important prerequisites for achieving the full potential of the investments in technology (Boyer & McDermott, 1999).

Several and quite different experiences are collected by the managers and supervisors, as well as operators and maintainers. The positive effect of the knowledge gains of each player is often decreased as planning, failure detection and repair are seldom executed by the same people. Use-based scheduling plans are often based on the machine deliverer prescriptions, rather than on the failure-based maintenance modelling. The historical average data on the base of such plans might have in consideration different realities and environments than the real one of the company. Conversely, integrated information systems, as well as the setup of concurrent and collaborative multidisciplinary teams are in the base on an optimum maintenance planning. Similarly, effectively integrating maintenance experiences in the design process requires feedback of data to purchasing and machine constructors and the use of cross-functional design teams (Jonsson, 2000).

Hence, the integration of the key the organizational functions experiences and goals into the decision level, especially in maintenance, assumes high importance as humans are involved in the various decisions related to maintenance and execution of tasks. Maintenance management processes are continuous closed loop processes in which feedback is used to lead to continuous improvement (Marquez & Gupta, 2006).

3. The Continental company

3.1 The Continental Group

Continental was founded in Hanover in 1871 as the stock corporation “Continental-Caoutchouc- und Gutta-Percha Compagnie”. Manufacturing at the main factory in Hanover included soft rubber products, rubberized fabrics, and solid tires for carriages and bicycles.

In 1898, initial successes in development and production were celebrated with the production of automobile pneumatic tires with a plain tread. At the turn of the century Continental balloon fabric was used to seal the gas cells of the first German airship. In 1904 Continental became the first company in the world to develop grooved tires for automobiles, in 1905 we commenced production of rivet anti-skid tires, similar to the later studded tires, and three years later we invented the detachable wheel rim for touring cars. In 1909, French aviator Louis Blériot was the first person to fly the English Channel. The flying surfaces of his monoplane were covered with Continental Aeroplan material.

In the late 1920s, the company merged with major companies in the rubber industry to form “Continental Gummi-Werke AG”.

In 1951 we commenced production of steel cord conveyor belts. In 1955, we were the first company to develop air springs for trucks and buses. Series production of belted tires began in 1960. Around 30 years later we brought the first environmentally friendly tires for passenger cars onto the market. In 1995 the Automotive Systems division was established to intensify the systems business with the automotive industry. We presented the key technology for hybrid drive systems back in 1997.

Today, Continental ranks among the top 5 automotive suppliers worldwide.

As a supplier of brake systems, systems and components for powertrains and chassis, instrumentation, infotainment solutions, vehicle electronics, tires and technical elastomers, Continental contributes to enhanced driving safety and global climate protection. Continental is also a competent partner in networked automobile communication.

With around 170,000 employees (Status: December 31, 2012) in 46 countries, the Continental Corporation is divided into the Automotive Group and the Rubber Group, and consists of five divisions:

- Chassis & Safety embraces the company’s core competence in networked driving safety, brakes, driver assistance, passive safety and chassis components.
- Powertrain represents innovative and efficient system solutions for vehicle powertrains.

- Interior combines all activities relating to the presentation and management of information in the vehicle.
- Tires offers the right tires for every application – from passenger cars through trucks, buses and construction site vehicles to special vehicles, bicycles and motorcycles. Continental tires stand for excellent transmission of forces, exceptionally reliable tracking in all weather conditions and high cost effectiveness.
- ContiTech develops and produces functional parts, components, and systems for the automotive industry and for other key industries.

Table 2: Continental AG revenue table

	2012	2011
Sales (millions of euros)	32,736.2	30,504.9
EBIT[1] (millions of euros)	3,073.4	2,596.9
Adjusted EBIT[2] (millions of euros)	3,522.4	3,040.9
Employees	169,639	163,788

[1] Earnings before interest and taxes

[2] Before amortization on intangible assets from purchase price allocation, changes in the scope of consolidation, and special effects.

3.2 Continental in Portugal

3.2.1 Company History

At the end of the 1980's, MABOR company was and old-fashioned plant with serious economic and financial problems. This company – Manufatura Nacional de Borracha (Mabor) – was a joint-venture with the American General Tire, which produced car tires and chambers.

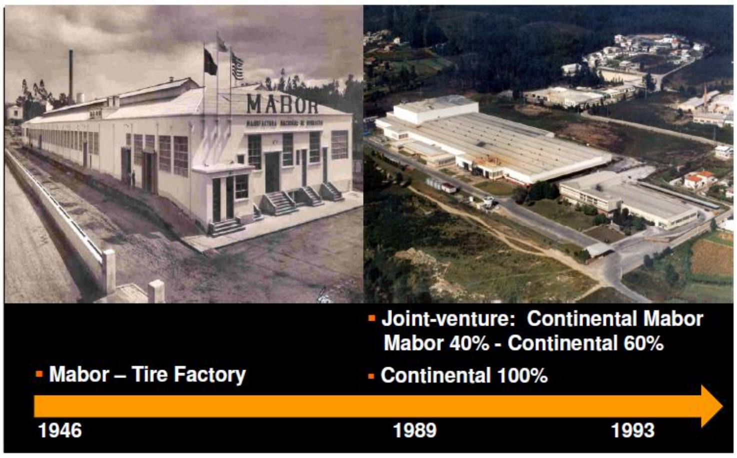


Figure 9: From Mabor to Continental Mabor

In 1989/1990, Continental AG and the Portuguese company Mabor establish a joint venture for the production of tires in Lousado, Mabor (40%) and Continental AG (60%). In 1993, Continental AG takes complete control of Lousado tire activities (fig. 9).

The restructuring project of 1990 transformed the old production facilities of Mabor into one of the modern tire factories. In 2008 the SUV Project updated the plant for production of 19'' rims tires and with larger speed index, especially to supply SUV (Sport Utility Vehicles) of important car manufacturers. In the end of 2010 the current running expansion project permitted to continue this permanent growth of the plant, with the project Route 17/20, which will prepare Continental Mabor to produce up to 20 million tires year, including 6 million of UUHP (Ultra Ultra-High Performance) tires (fig. 10).

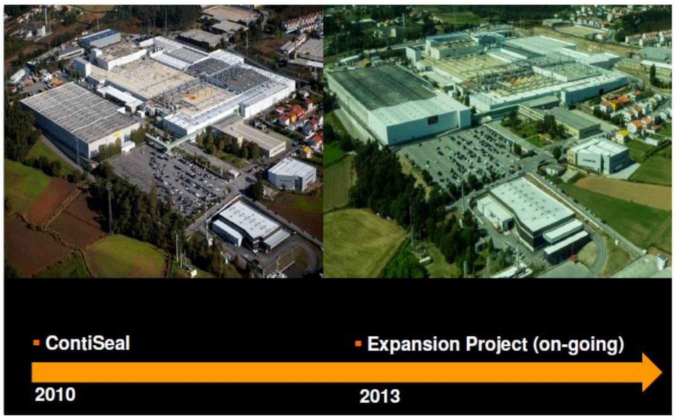


Figure 10: Continental Mabor after the restructuring projects

There are currently in Portugal, five companies belonging to the Continental group: Continental Mabor (light truck and passenger's car tires production), Continental Pneus (Sales Company), ITA (textile plant), Continental Lemmerz (tire-wheel assembly) and Continental Teves (braking systems production).

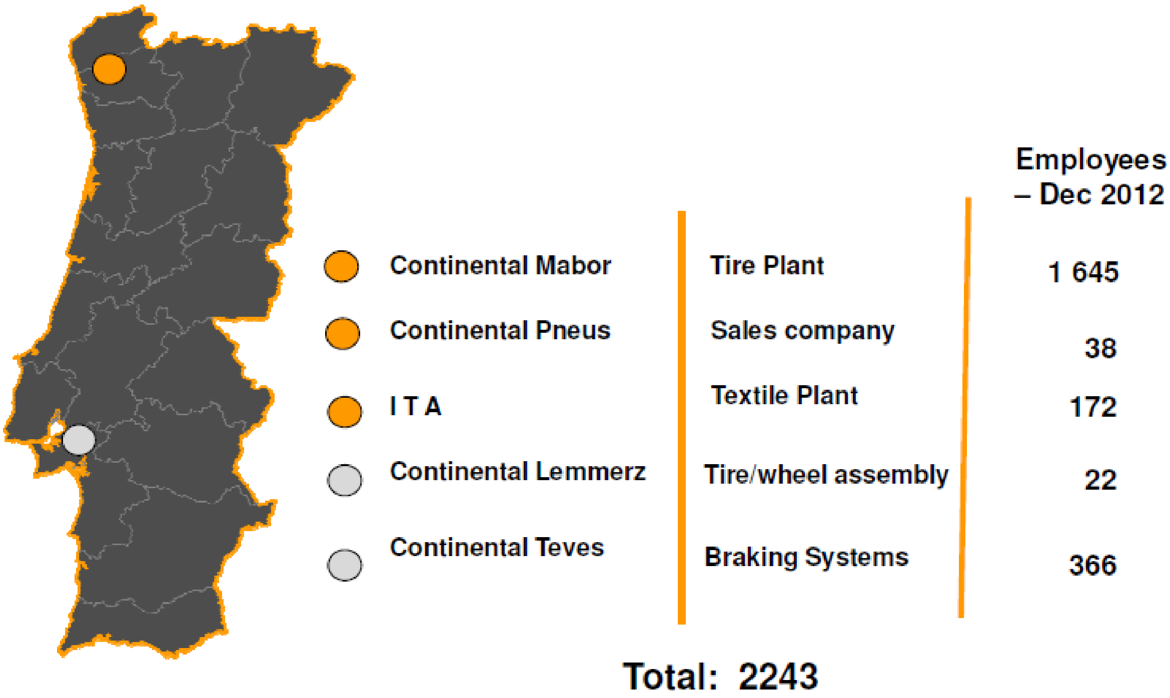


Figure 11: Continental employees in Portugal

At the end of 2012, Continental Mabor had total 1645 employees (fig. 11). There was an increasing of the workforce, to give an answer to the emerging needs to follow the operation growth of the company, as well as its expansion, including the needed support to the technical areas.

The evolution of the company employees might be seen in the following chart:

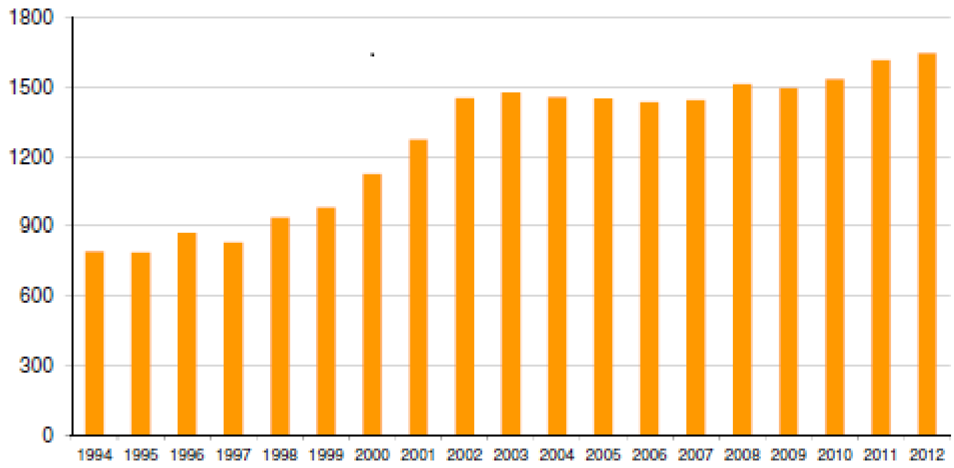


Figure 12: Continental manning evolution

3.2.2 Company organization

The Continental Mabor tire plant is organized within the Continental Group, is defined as shown in the figure 13. There are nine main departments being that a new one is being created (not yet in the present diagram) the Manufacturing and Innovation Projects department.

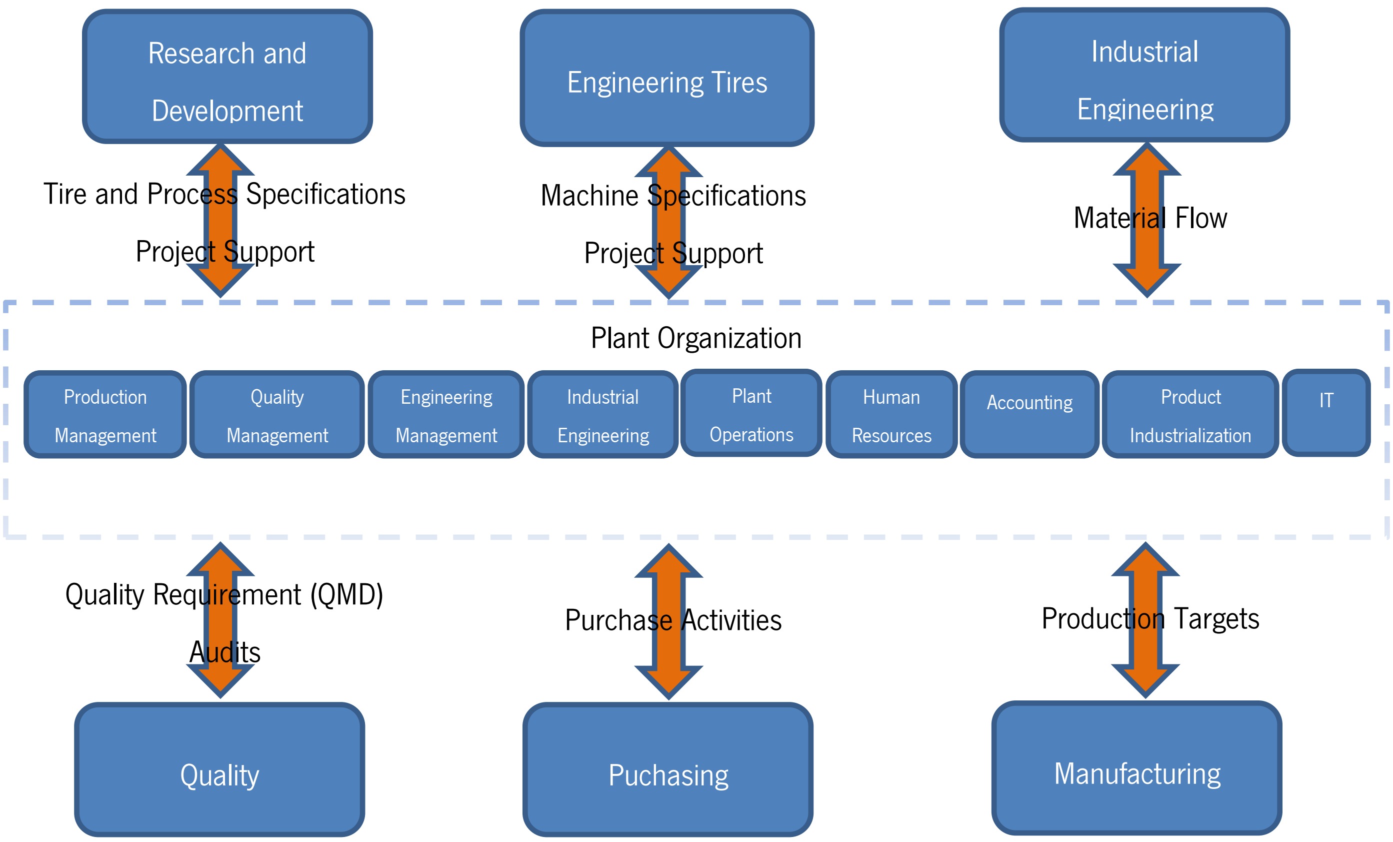


Figure 13: Continental Mabor's organization

3.2.3 Company products

Continental Mabor has in its portfolio the production of Passenger and Light Truck tires, either winter and summer tires, currently covering only a range rims starting from 14 inches up to 20 inches, in the following distribution seen in the figure 14.

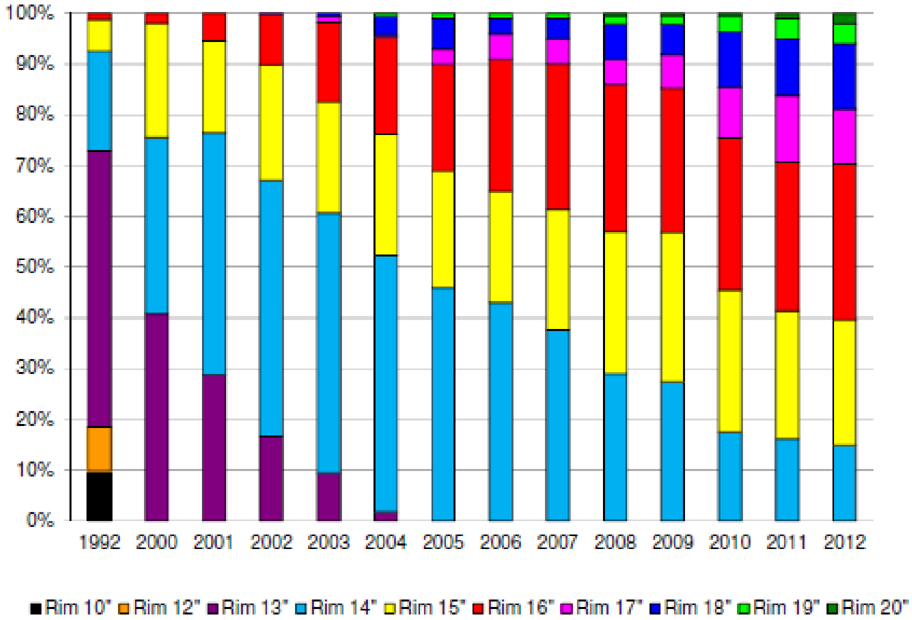


Figure 14: Continental Mabor production by rim size

The running expansion project will allow the plant to produce up to 24 inches tires, the most part of them due to the production of the so-called UUHP tires, which are characterized by this big rim sizes and most of all by the high speed required by these types of tires. Regarding the tire's segment, the Continental Mabor's production is divided according the figure 15.

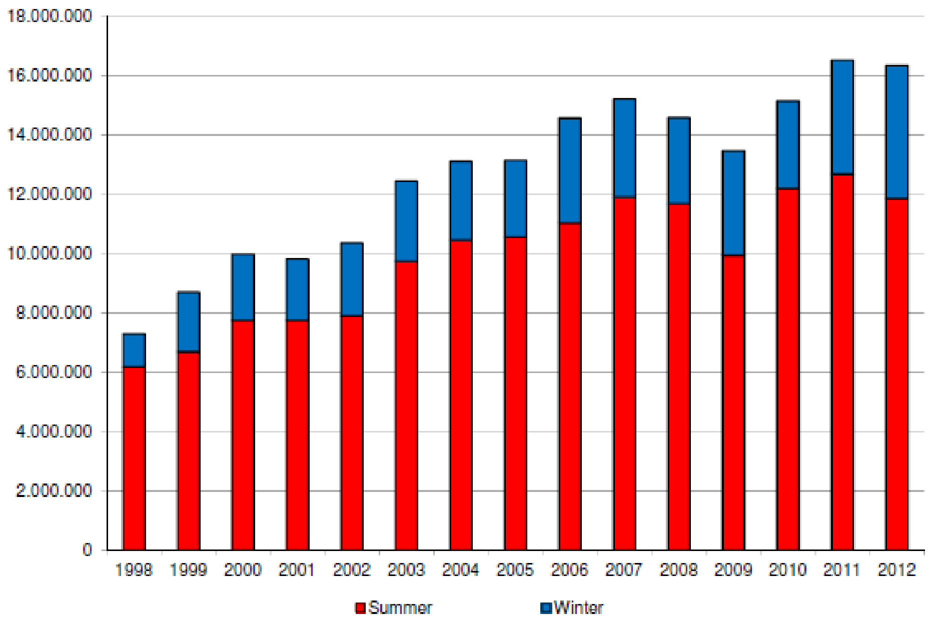


Figure 15: Continental Mabor production by segments

In terms of brands, as Continental tire group is a worldwide company which includes several subsidiaries, as Continental Mabor, that once in the past had their own brand, there are also several brands being part of the production portfolio. Brands as Continental, Uniroyal, Semperit, Mabor, Barum, Gislaved/Viking and General Tire among others are produced in Continental Mabor, as it is seen in the figure 16.

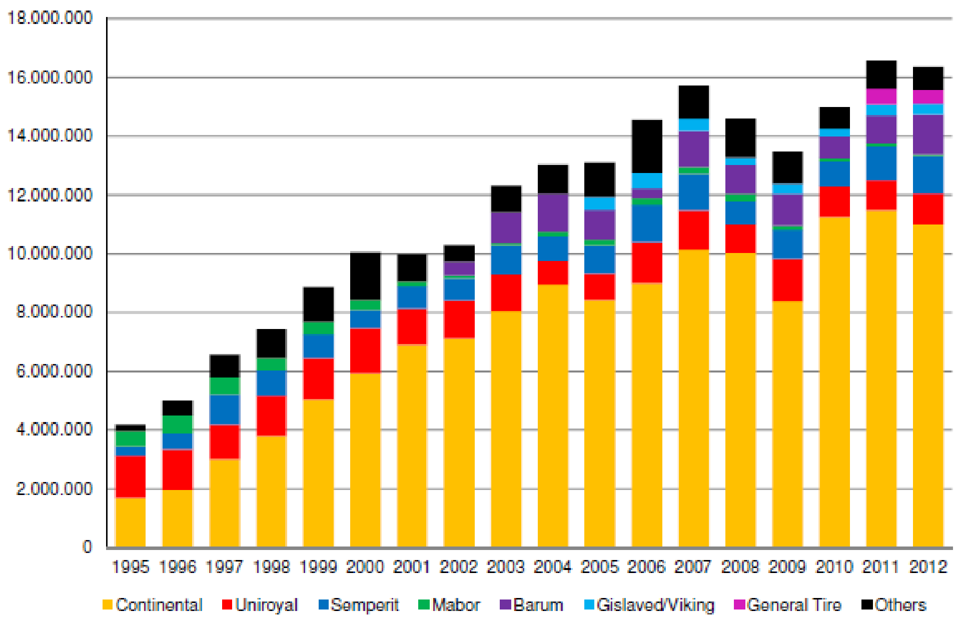


Figure 16: Continental Mabor 's prodution brands

The tires produced in the company might be sold directly to the final customer or to the car constructor. In this last case, original equipment (OE) market, the customer demands are even higher, so the rate of sales to this market is a good indicator of the company performance and prestige.

The evolution percentage of the OE market sales has a grown tendency, as seen in the figure 17.

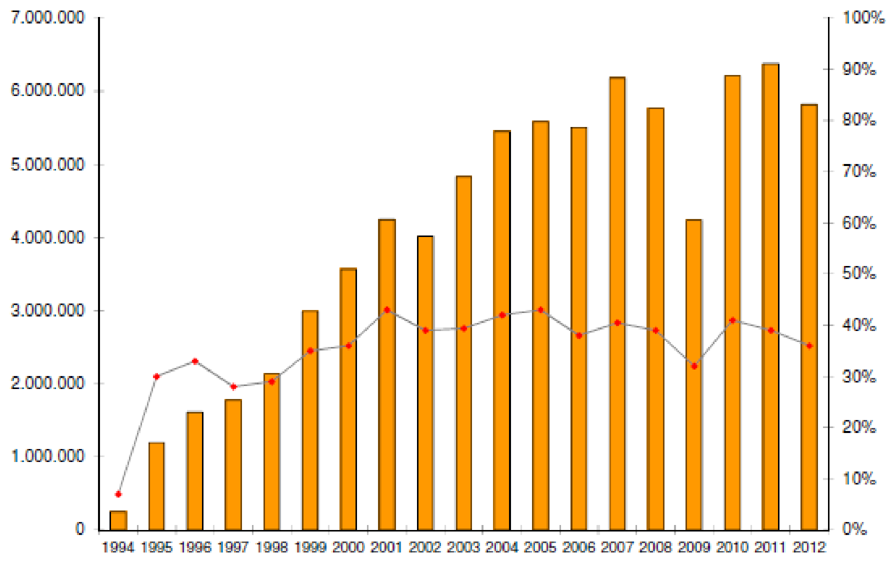


Figure 17: Continental Mabor OE production

In 1993, at the beginning of the Continental Mabor restructuring project, the only OE customer of the company was Opel. The actual OE portfolio of the company is extensive and includes several premium car constructors as Porche, Jaguar, Mercedes-Benz, BMW and Audi, among others (figure 18). Only three car constructors consume about 50% of the company production (figure 19).

Figure 18: Continental Mabor OE customers

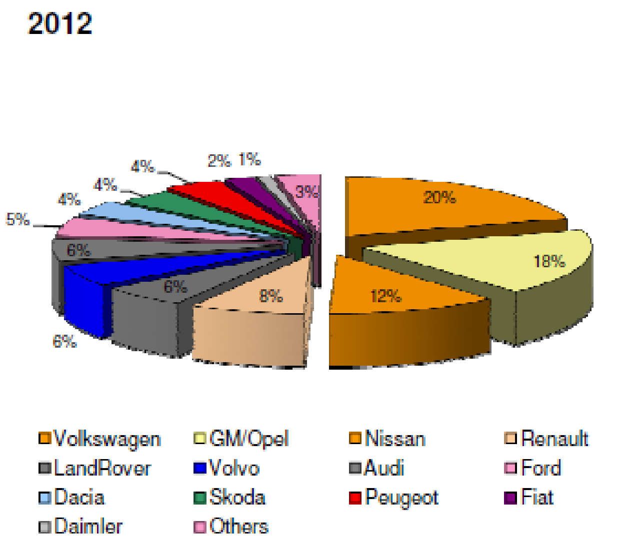


Figure 19: Continental Mabor production distribution by OE customer

To finish the company market characterization, the sales distribuition around the world shows that the Portuguese market is, as expected, a small representative of the sales with only 2% of the total, which is in its big part consumed by the German market (figure 20). However is also significant the amount of tires sent to Belgium and the United Kingdom.

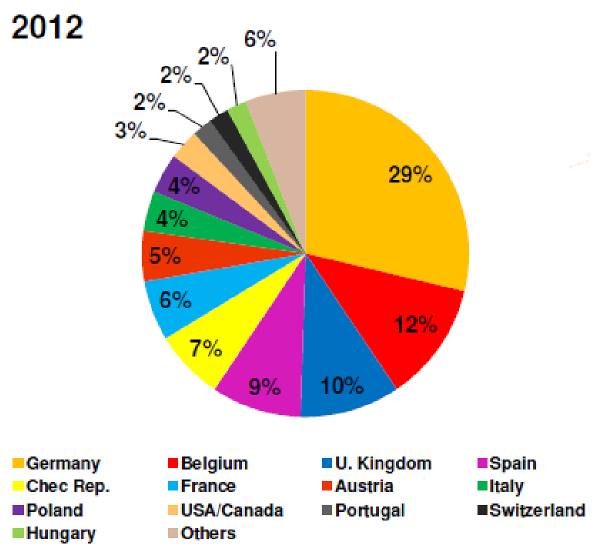


Figure 20: Continental Mabor's sales by country

3.3 The Continental Mabor's productive process

3.3.1 The product and the productive process

The main constitution of a tire might be described by figure 21.

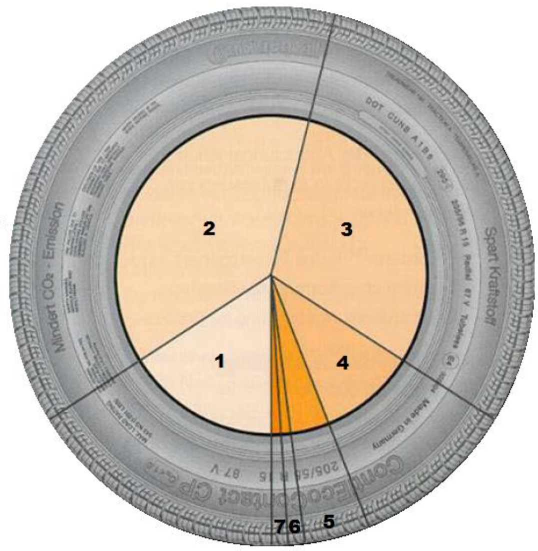


Figure 21: The tire constitution

1 – Carrier of strength (steel, rayon, polyester, nylon)	16%
2 – Rubber (natural and synthetic)	38%
3 – Fillers (carbon black, silica)	30%
4 – Softner (oil, wax)	10%
5 – Chemicals for vulcanization (sulfur, accelerator, activator)	4%
6 – Antioxidant	1%
7 – Miscellaneous	1%

The productive flow includes the following processes and machines as shortly described in the figure 22.

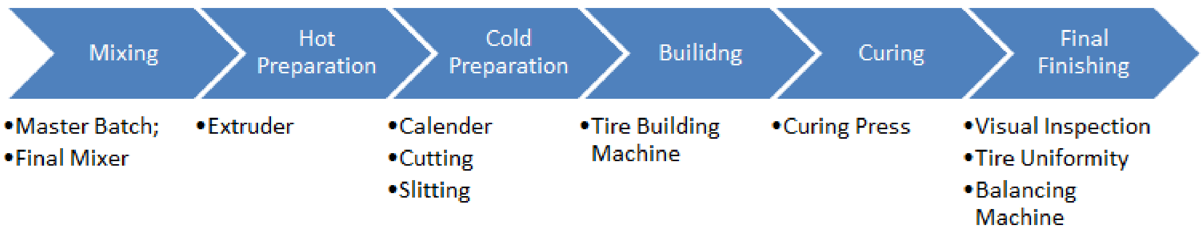


Figure 22: The productive process

From Mixing to Final Finishing, several different and complex processes constitute the building of a tire. Thus, a wide range of skills and expertise in several different areas of knowledge, from chemical to physics, is needed in order to achieve with the desired quality the final product, the tire.

3.4 Maintenance Departments organization at Continental Mabor

3.4.1 Maintenance departments and responsibilities

This section characterises the Engineering division in the company and how the Maintenance function is included in this division. The Maintenance function at Continental Mabor is under the responsibility of the Engineering Management.

As we can see in the figure 23, the company has three Engineering departments plus one Energy and Utilities department, all of them reporting to the Plant Engineering Manager.

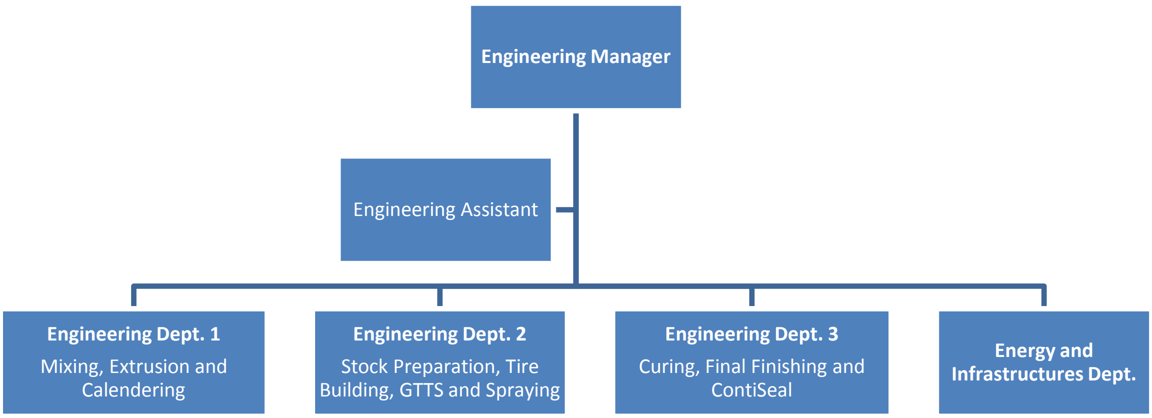


Figure 23: Continental Mabor's Engineering organization

The mission of the Plant Engineering Manager is to conduct the Engineering Department, according the strategies defined by the company, through the coordination of actions undertaken by their technical team, geared to meet the expectations of the internal customers in each service provided: to ensure the implementation of investment projects according to the plan, the optimization of the activities related with the production equipment, tools and utilities maintenance, to ensure the availability of energy resources, and to increase the overall economic and financial results of company' activity.

The main activity of each engineering department is to give the best maintenance support in order to have each machine working as they were design to, pushing them to challenging production quantity and quality levels. Thus, each engineering department is affected to specifics Production areas, in a way that each personnel group can expertise in the specifics production equipment characteristics.

In this way, Engineering Department 1 (ED1) is responsible to give support to the Mixing and Extrusion areas, the so called Hot Preparation Department. This department has the biggest production machines in its machinery park. Engineering Department 2 (ED2) gives support to the Hot (partly) and Cold Preparation area, which includes the construction of beads, bead apex, cutting of textile and steel cord material, slitting as well as includes the Tire Building department (when the tires gather all its materials but not the finals shape). ED2 also gives support to the Green Tire Conveyor System (GTTS), as well as to the Spraying area. Finally, the Engineering Department 3 (ED3) is supporting the Curing Press, Final Finishing and ContiSeal areas. The Energy and Infrastructures Department has a transversal role in the management and support to the energy issues in the overall plant.

The Engineering Department manager has the responsibility of manage and monitor his department activities, in accordance with the guidelines of the plant engineering management, optimizing and maximizing the available resources (human and machine resources), and to ensure the installation of equipment according the plan.

The present work was done in the Engineering Dept. 2, which has the organization seen in the figure 24.

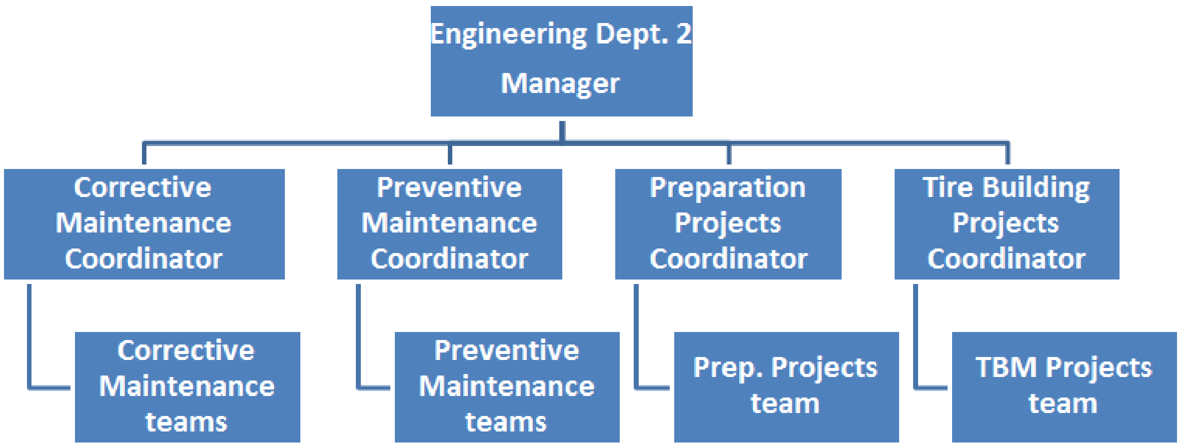


Figure 24: ED2's organization

3.4.2 Maintenance teams organization in the ED2

Before the present project, Maintenance strategy defined in the ED2 was settled in two single approaches:

- Corrective Maintenance with a Failure Based Maintenance focused approach
- Preventive Maintenance with an Used Based Maintenance focused approach

The Corrective Maintenance teams had in total 27 technicians divide into 5 groups: three groups giving support to production in three shifts, rotating weekly, from Monday to Friday and two shifts working during the weekend. The weekend elements had to come two days during the week in order to totalize the 40 week hours foreseen in the Portuguese law. The week groups, namely A, B and C, had 5 elements and the weekend groups, D and E, had 6 elements.

The shifts organization in Continental is in the following way:

- It was settled that the working day start at 8:00 instead of 0:00;
- The week starts Monday at 8:00 and finishes Saturday at 8:00:
- There are three week shifts, from 8:00 to 16:00, 16:00 to 24:00 and 0:00 to 8:00, first, second and third shifts by this order.
- There is no fourth shift, meaning that the first weekend shift is the fifth shift;
- The weekends shifts start at 8:00 to 19:00 (Saturday), 19:00 to 6:00 (Saturday to Sunday), 6:00 to 14:00 and 14:00 to 24:00 (Sunday), 0:00 to 8:00 (Monday), the fifth, sixth, seventh, eighth and ninth shifts by this order.

As already mentioned, the weekend teams had one additional element comparing with the week groups.

The number of technicians needed by team to give support to the Production needs in the Corrective Maintenance, is six, being three electricians and 3 mechanics. The weekend groups had this configuration completed in the group definition. In a way to guarantee this same distribution to the week groups, the weekend resources allocation (table 3) during the week (as each technician has to work additionally two days per week), was divided in two strategies:

- to reinforce the Corrective Maintenance teams of first, second and third shifts by the electricians;
- to reinforce the Preventive Maintenance teams with the mechanics.

Table 3: Resources allocation table before the iCBM implementation

ESCALA DA EQ. FIM DE SEMANA - SEMANA 5					
	2ª Feira	3ª Feira	4ª Feira	5ª Feira	6ª Feira
1º Turno	E1	E1		D3	D1
2º Turno	E2	E4	E4	D2	D2
3º Turno	D1/E3	E3	D4	E2	D3

ESCALA DA EQ. FIM DE SEMANA - SEMANA 6					
	2ª Feira	3ª Feira	4ª Feira	5ª Feira	6ª Feira
1º Turno			E4	E3	D1/E1
2º Turno	D1/D4	D3	D3	E2	E2
3º Turno	E1	D2	D2	E4	E3

ESCALA DA EQ. FIM DE SEMANA - SEMANA 7					
	2ª Feira	3ª Feira	4ª Feira	5ª Feira	6ª Feira
1º Turno	E4	E4	D3		
2º Turno	E1	E3	E3	D1/D2	D1/D3
3º Turno	D4	E2	E2	E1	D2

3.4.3 The Corrective Maintenance activities in the ED2

The FBM activities of the Corrective Maintenance teams are based on the plant CMMS (Computer Maintenance Management System), the SAP PM, in which the repair orders are created, managed and reported in the end of each activity.

The FBM repair order is created by the machine operator, directly in the SAP PM, in a quick entry form (figure 25), where he identify the machine that has the malfunction, the specific equipment (if known), a short description (usually he informs here if the failure is electrical or mechanic, in order to allow the Corrective Maintenance team to know the more adequate technician to overtake the task) and its employee number. The order is created when the operator press one of the two keys available: F5 to inform that this is a critical failure as the machine is stopped by this reason or F6 to inform that there is a need of a repair due to a machine malfunction even though the machine is still running (maybe slower, or other similar reason that putting the machine in a low efficiency mode status).

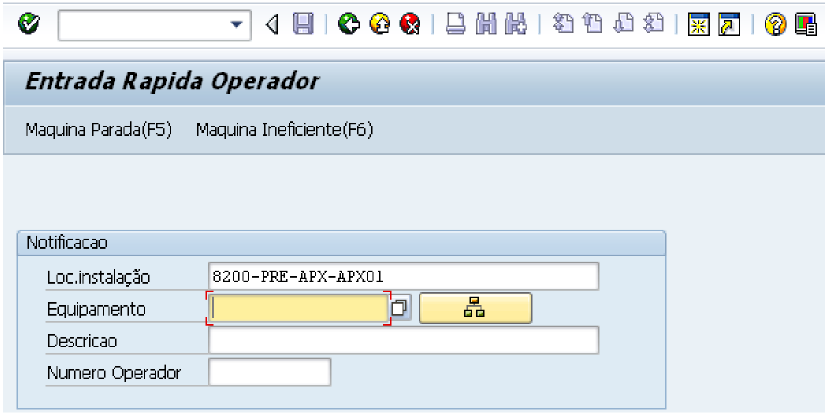
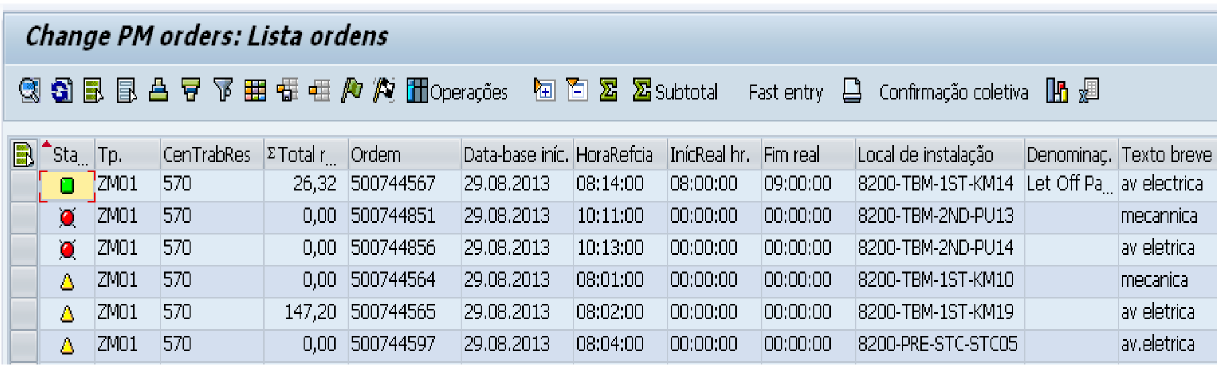


Figure 25: SAP quick entry form for FBM work orders

This order will fall in a pool of orders (figure 26), available in the operations centre: the tool shop. In this list, each technician will check by a red circle that a new repair request has arrived and may get additional information before take the decision of overtaking the request. He will check the type of failure, whether is electrical or mechanic, as well as which could be more critical according it nature, machine stopped which will appear as ZM01 order type, or machine running in low efficiency, which will be showed in the screen as ZM03 orders.



Change PM orders: Lista ordens

Sta...	Tp.	CenTrabRes	ΣTotal r...	Ordem	Data-base inic.	HoraRefcia	InicReal hr.	Fim real	Local de instalação	Denominaç.	Texto breve
	ZM01	570	26,32	500744567	29.08.2013	08:14:00	08:00:00	09:00:00	8200-TBM-1ST-KM14	Let Off Pa...	av electrica
	ZM01	570	0,00	500744851	29.08.2013	10:11:00	00:00:00	00:00:00	8200-TBM-2ND-PU13		mecannica
	ZM01	570	0,00	500744856	29.08.2013	10:13:00	00:00:00	00:00:00	8200-TBM-2ND-PU14		av eletrica
	ZM01	570	0,00	500744564	29.08.2013	08:01:00	00:00:00	00:00:00	8200-TBM-1ST-KM10		mecanica
	ZM01	570	147,20	500744565	29.08.2013	08:02:00	00:00:00	00:00:00	8200-TBM-1ST-KM19		av eletrica
	ZM01	570	0,00	500744597	29.08.2013	08:04:00	00:00:00	00:00:00	8200-PRE-STC-STC05		av.eletrica

Figure 26: FBM orders list

There are three possible statuses for the FBM work orders, as we can see in the figure 27.

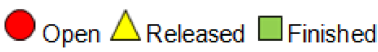


Figure 27: Maintenance order's states

By the moment the technician decides to undertake one order, he will write is employee number in the order line of the list, and after save, status will change to “released”, represented by a yellow triangle.

During the repair, the technician is responsible for the machine, he has to make the diagnosis of the failure and to decide whether he is capable to solve the problem or needs to involve more people from team or others. He has the chance to contact colleagues from Preventive Maintenance (if available in the plant). Usually if the problem becomes critical, the team leader is informed, and this one will be the one in charge to contact any other support level outside of the team. In this group of support is also included the Corrective Maintenance coordinator, as well as the engineers of the Projects team.

Likewise, the technician is autonomous to decide whether is necessary to replace a component by a new (or repaired) one, from the spare parts stock. For costs management there is also a risk in this task as, by the pressure of the machine's downtime, the maintainer might have the temptation of quickly decide for the replacement.

After having the machine running, the technician has return to the repair order, so that elaborates the intervention report (figure 28), before to close it.

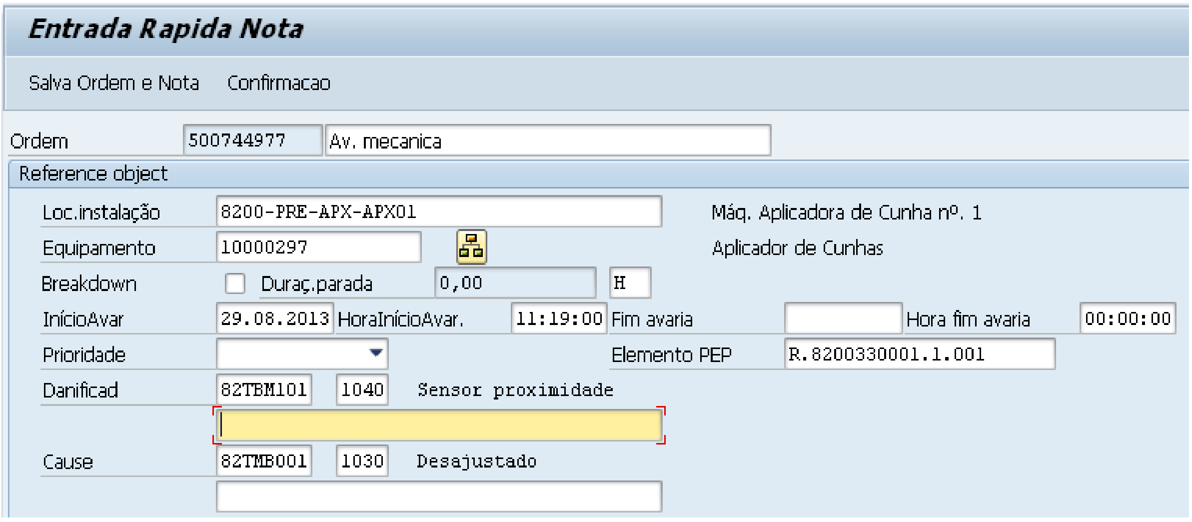


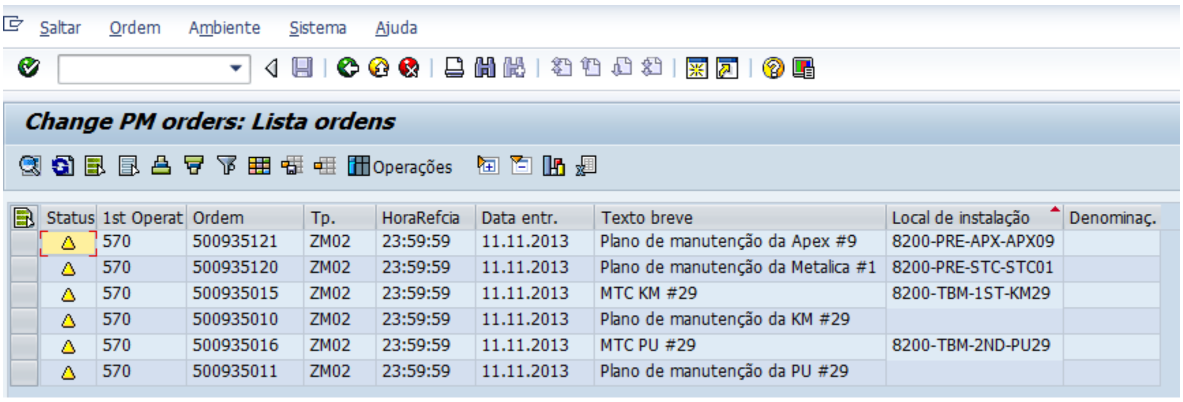
Figure 28: FBM work order report

This might be considered the heart of its action, as likewise to having the machine available again faster than possible, he as the responsibility to describe as better as possible the occurrence for future analysis. After saving, the order will be putted in the "closed" status, represented by a green square.

3.4.4 The Preventive Maintenance activities in the ED2

The Preventive Maintenance teams had in total 16 elements which were divided in three groups: one responsible by the preventive maintenance tasks of the Hot and Cold Preparation areas, the other responsible for the support to the Tire Building, Spraying and GTTS areas, and the last one responsible to ensure the MTC (Machine Tolerance Check). The reason behind this division was to allow an expertise within each working area, each machine type and its specific components knowledge. The experience, when comparing with the past, shows goods results in terms of contribution for the reliability of each group of machines.

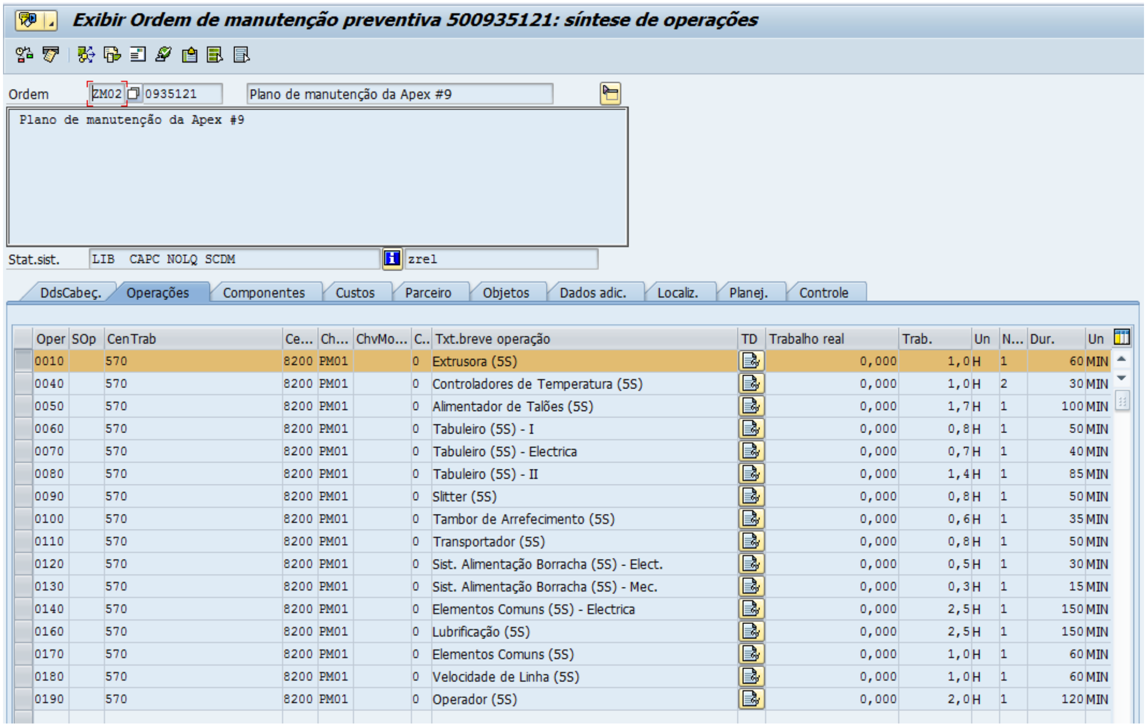
Again, the preventive maintenance orders management are similarly based in the SAP PM, in which case the order initiator is the Preventive Maintenance coordinator.



Status	1st Operat	Ordem	Tp.	HoraRefcia	Data entr.	Texto breve	Local de instalação	Denominaç.
	570	500935121	ZM02	23:59:59	11.11.2013	Plano de manutenção da Apex #9	8200-PRE-APX-APX09	
	570	500935120	ZM02	23:59:59	11.11.2013	Plano de manutenção da Metalica #1	8200-PRE-STC-STC01	
	570	500935015	ZM02	23:59:59	11.11.2013	MTC KM #29	8200-TBM-1ST-KM29	
	570	500935010	ZM02	23:59:59	11.11.2013	Plano de manutenção da KM #29		
	570	500935016	ZM02	23:59:59	11.11.2013	MTC PU #29	8200-TBM-2ND-PU29	
	570	500935011	ZM02	23:59:59	11.11.2013	Plano de manutenção da PU #29		

Figure 29: UBM order's list

As an UBM approach, the preventive maintenance tasks (figure 29) are scheduled for each machine based on time of use, number of operation cycles executed, taking into account the machine supplier recommendation, each component behaviour knowledge and of course, the state of the machine in the previous moment of this activity. Additionally, these routines (figure 30) are influenced by the information coming from the Production operators.



Exibir Ordem de manutenção preventiva 500935121: síntese de operações

Ordem ZM02 0935121 Plano de manutenção da Apex #9

Plano de manutenção da Apex #9

Stat.sist. LIB CAPC NOLQ SCDM zrel

Oper	SOp	CenTrab	Ce...	Ch...	ChvMo...	C..	Txt.breve operação	TD	Trabalho real	Trab.	Un	N...	Dur.	Un
0010		570	8200	PM01		0	Extrusora (5S)		0,000	1,0	H	1	60	MIN
0040		570	8200	PM01		0	Controladores de Temperatura (5S)		0,000	1,0	H	2	30	MIN
0050		570	8200	PM01		0	Alimentador de Talões (5S)		0,000	1,7	H	1	100	MIN
0060		570	8200	PM01		0	Tabuleiro (5S) - I		0,000	0,8	H	1	50	MIN
0070		570	8200	PM01		0	Tabuleiro (5S) - Electrica		0,000	0,7	H	1	40	MIN
0080		570	8200	PM01		0	Tabuleiro (5S) - II		0,000	1,4	H	1	85	MIN
0090		570	8200	PM01		0	Slitter (5S)		0,000	0,8	H	1	50	MIN
0100		570	8200	PM01		0	Tambor de Arrefecimento (5S)		0,000	0,6	H	1	35	MIN
0110		570	8200	PM01		0	Transportador (5S)		0,000	0,8	H	1	50	MIN
0120		570	8200	PM01		0	Sist. Alimentação Borracha (5S) - Elect.		0,000	0,5	H	1	30	MIN
0130		570	8200	PM01		0	Sist. Alimentação Borracha (5S) - Mec.		0,000	0,3	H	1	15	MIN
0140		570	8200	PM01		0	Elementos Comuns (5S) - Electrica		0,000	2,5	H	1	150	MIN
0160		570	8200	PM01		0	Lubrificação (5S)		0,000	2,5	H	1	150	MIN
0170		570	8200	PM01		0	Elementos Comuns (5S)		0,000	1,0	H	1	60	MIN
0180		570	8200	PM01		0	Velocidade de Linha (5S)		0,000	1,0	H	1	60	MIN
0190		570	8200	PM01		0	Operador (5S)		0,000	2,0	H	1	120	MIN

Figure 30: Example of an UBM work order

Each main task has a description of the several detailed actions to execute in order to fulfil the maintenance plans, most of them of the type “to verify, “to check” (figure 31).

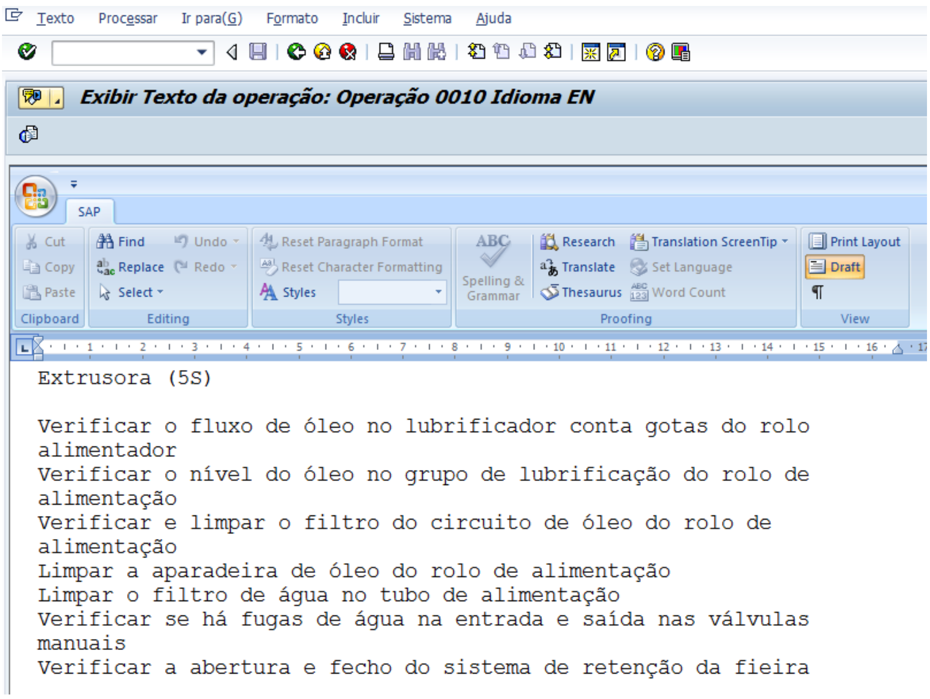


Figure 31: UBM detailed task description

The ED2 preventive maintenance strategy also include some predictive actions as the electrical consumption measuring among others, as well as the reading and analysis of the corrective maintenance activity reports. In the same way, the daily dialogue with the Production operators and management is also a source of information about the machine state, which sometimes has influence in the maintenance plan. However, this approach is not totally effective as in many cases there is the need to check the problem having the machine working and to remain some hours doing this evaluation and this is not the case of the preventive maintenance activity as its settled in this department. A considerable amount of tasks demands that the machine has to be switched off, maybe dismantled to replace a component, etc.

3.4.5 Challenges of the ED2 maintenance strategy

The described organization demonstrate a strategy so far focused in the support to the Production needs regarding the best answer to the failures or breakdowns by the Corrective Maintenance teams, as well as a concern to avoid catastrophic failures by the activity of a mature and well organized Preventive Maintenance group.

However, both experiences revealed the need of a different approach in order to achieve even better results and increase reliability as well as to set a bigger proactive maintenance activity.

Under the pressure of a breakdown, the maintainers are focused in giving back the machine to Production. Each minute, each hour may mean the objective not being achieved in the end of the day and to loose tires, which will never be recovered. It is important to have in mind that the plant works twenty four hours a day, seven days a week, which means that there is no place to recover production by overtime. Hence, during the repair task, the technician try to restore the machine in the same level as it was built to, but if there is a chance to give back the machine running, even if not 100% recovered, there is a big temptation and pressure to do it so. Thereby, there are two questions: when will be done the final repair? By whom will it be done?

Several risks arise in this moment: to be forgotten, to be not well reported in the CMMS or even to be passed to a team that will also not have the conditions to complete the repair. Usually the team in the best position to receive this work is the UBM or the preventive maintenance team.

However this option is not always the best as, for instance, some type of failures or problems need to be observed for a large time during the component or machine operation. This is not the case of the

UBM activity as this team receives the machine, stopped and without operator, for a predefined time in which they have to execute the planned replacement or overhaul tasks.

3.4.6 Machinery under the responsibility of the Engineering Dept. 2 (ED2)

The main production equipment under the responsibility of the ED2, is shortly described as follows.

Bead winding machines

Figure 32: Beadwinder machines

In the Bead Winding machines (figure 32) are constructed the beads, which are the element that guarantees the perfect adaptation of the tire to the wheel.

Apex machines

Figure 33: a view of an Apex machine

The Apex machine (figure 33) produces and provides the assembly of a rubber strip to each bead of a tire.

Textile cord cutting lines

Figure 34: Textile cutting machine

The textile cord cutting lines (figure 34) cuts the textile (rayon or polyester) rolls coming from the calendar, in a specific angle range, (mostly being 90˚) and a specific width according the type of tire.

Maxi slitter / Mini Slitter / Cap Strip

Figure 35: Maxi and mini slitter machines

The cut of calendered material for full or jointless cap-ply (figure 35) are made in the maxi-slitter and minislitter correspondingly. In the case of the Cap Strip machines, the jointless cap-ply is obtained by an extrusion process, thus not needing calendar material.

Steel cord cutting lines

Figure 36: Steel cord cutting machine

The cutting of steel cord rolls coming from calendar into steel cord Chafer or Breaker is made in this type of machines (figure 36). The material's specific angle and width is defined according the type of tire to be produced.

Tire Building machine

The tire production in made of in two stages, starting with the carcass assembly in the KM machine (figure 37).

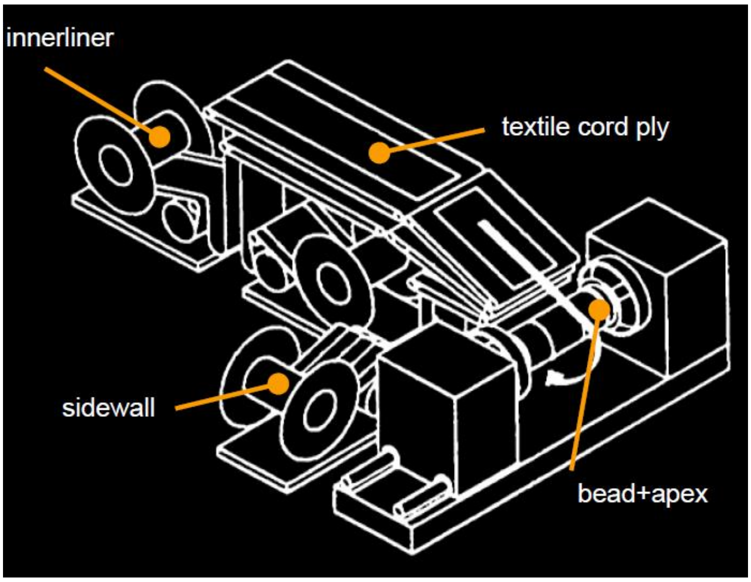


Figure 37: Carcass machine

The carcass integrates previously produced materials such as innerliner, textile plies, sidewalls and bead apex.

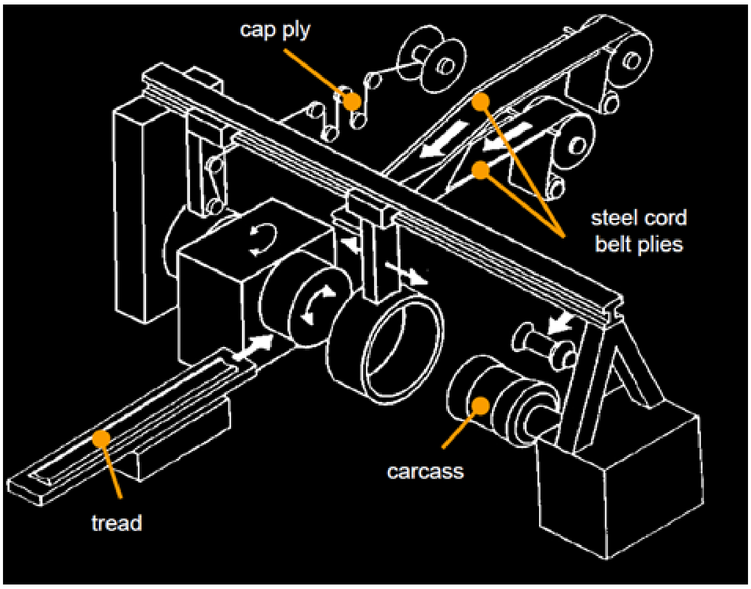


Figure 38: The second stage tire buiding machine

In the second stage, the so called package (with breaker, cap-ply and tread) joins the carcass to build the complete tire by the first time. This machine is also known as the PU machine (figure 38).

Green Tire Transport System, Spraying machines and Green Tire Automatic Loaders

Before the next process phase, the tire is transported to a spraying machine, which lubricates the interior of the tire according the pre-requisites of the curing process. After this operation, the tires are loaded to carriers, in order to be moved to the next phase's machines. All this three machine type's maintenance is equally under the responsibility of the ED2.

4. The model of an Integrative Condition Based Maintenance

4.1 The iCBM concept

Most companies have in their maintenance function, a blend of two main strategies: failure based maintenance (FBM) and used base maintenance (UBM). Having already given prove of success, this approach for one hand allows to be "on the safe side" for any unpredictable event which could compromise production goals, and for the other hand establishes a strategy of avoidance of catastrophic failures which could seriously compromise production's capability.

Nevertheless these two strategies are no longer acceptable to achieve the overall goals of the organizations as both have serious efficiency losses: the random usage of the resources in a FBM as well as the high costs of the UBM approach due to its principle of components replacement or overhaul by a fixed-time or number of operations cycles knowing that this is seldom justifiable a small rate of components fail within the usually recommended periods, added to the reality that, both excessive frequency or under maintenance will decrease the production equipment availability (Eti et al., 2006).

The strategy is then reliability. In a way to remain competitive in the market, the maintenance strategy has to reflect the challenges of the mission that stands in having the equipment running by means of failure avoidance through high efficient predictive routines focusing in a positive contribution to the company's overall goals including costs reduction as strategy to improve the business profit margins (Eti et al., 2006). Based on this outlook, the main goal of the presented model is to avoid failures and improve the equipment's performance, changing accordingly their state (Rachidi et al., 2013).

This maintenance approach relies on the change of the reactive-focused maintenance paradigm to a proactive-focused approach integrating the available maintenance and manufacturing experiences and knowledge (Jonsson, 2000).

4.2 A concurrent maintenance strategy

The Integrated Condition Based Maintenance (iCBM) model uses a strategy of consensus between the company established maintenance teams in a concurrent and collaborative environment, with the aim of introducing the focus in the proactive maintenance practices, taking the best of best of each group. It is the beginning of a change that is required to happen fast but without turbulences which could put the organization goals in risk. In spite of gathering a wide range of maintenance strategies, the conducting line of the iCBM strategy will follow the Condition Based Maintenance policy, the proactive focused strategy by excellence (including also practices of Detection Based Maintenance) (AHC Tsang, 1995).
The big advantage of the iCBM strategy is to be based on the available maintenance teams and resources of the company, allowing changes and improvements with low or even no addition costs.
The first step of the iCBM implementation is, therefore, to enhance the connection between the existing maintenance teams (with appropriate training and teamwork with shared goals) in a way that the relationship between the teams grows from weak (as shown in the figure 39) to strong connections.

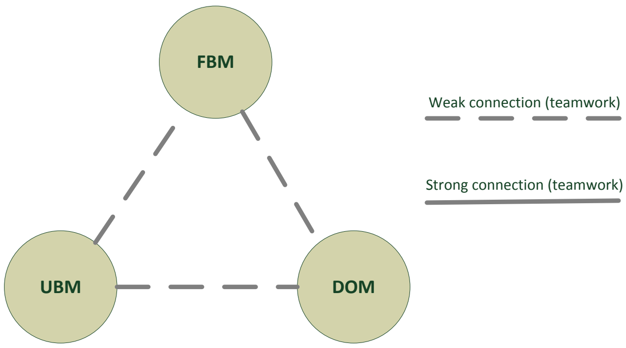


Figure 39 - The iCBM base constituition

The set of the iCBM strategy is therefore based on the creation of a new multidisciplinary maintenance team which integrates members of the existing teams, without substituting any of them (figure 40).

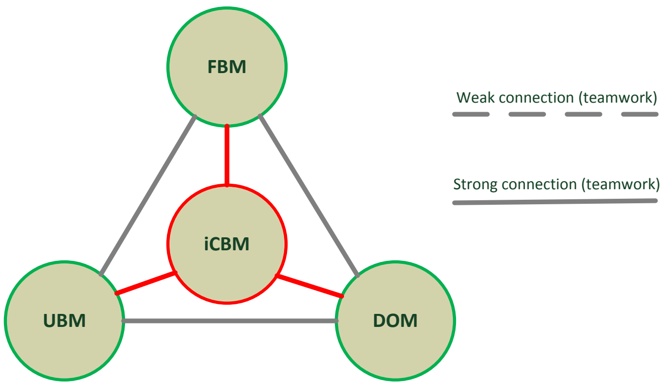


Figure 40 - iCBM

The new team is the connection between the teams and promote the top vision of the maintenance business needs and goals integrated in the company strategy.

As a concurrent team, decision-making models are defined; strong efforts are needed for the team coordination in order to manage conflicts and different opinions between the members.

In the iCBM environment, all the participants (coming from FBM, UBM and DOM/Projects teams) are invited to bring their experiences, their difficulties and their new ideas or suggestions (figure 41).

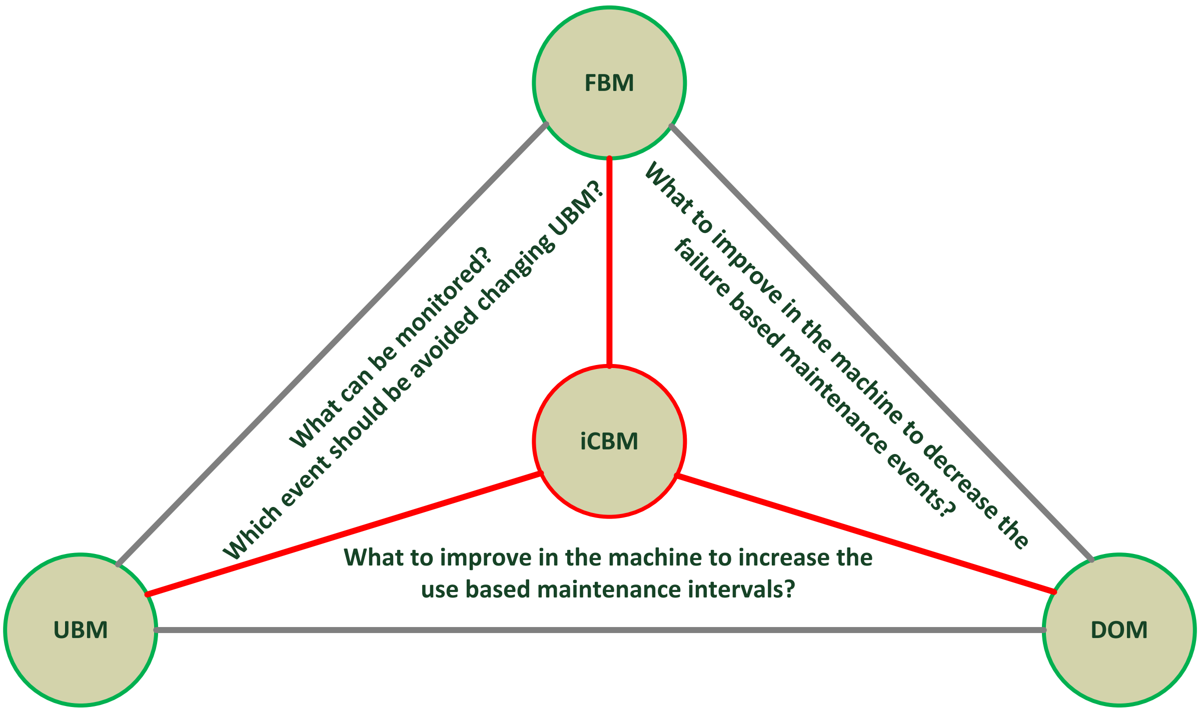


Figure 41 - iCBM discussions example

During each maintainer activity, each technician finds several needs that are not only within his hands to solve it:

- a repetitive breakdown that will never being solved unless a certain part of the machine to be changed, or the component to be replaced by a stronger one, or an operation to be improved;
- problems with repairs poorly done or only half done in a way to put the machine running as soon as possible;
- serious breakdowns which impact is so big that justify to invest in prediction measures;
- the opportunity to improve the maintainability of a machine during an old machine's retrofit;
- several others...

Although this strategy is based on the existing maintenance function teams, other functions (teams) might be integrated for improved results (procurement function, accounting, quality function, etc.) as shown in figure 42. Therefore, reliability-centred maintenance principles are foreseen in this model, as, with further development, it might have focus on the components requirements needs for the fulfilment of their functions with the least cost (Eti et al., 2006), using the know-how of this multidisciplinary team.

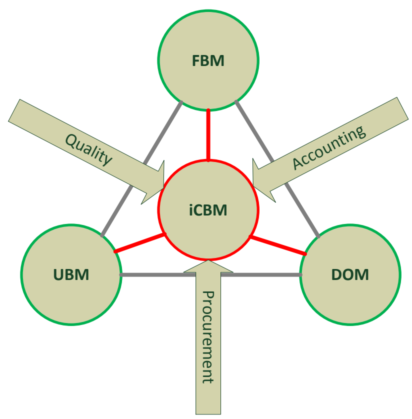


Figure 42 - Multidisciplinary team

The integration of the other company functions in the iCBM team is done in a different way than the integration of the core group (the group of the maintainers – FBM, UBM, and DOM).
Functions like Quality, Accounting, Procurement, Health and Safety, IT, Industrial Engineering or others, will be support members, occasionally invited to join the group to supply its activity with information and

all the relevant data needed to understand and improve the impact of Maintenance in the company daily life and goals.

Setting this approach, bringing faces from these functions to the iCBM team, as well as giving a maintenance face to each of that function, will allow a more efficient teamwork for any transversal topic related with the maintenance activity and its impact.

Either the maintainers will develop a more accurate responsiveness to aspects as quality, financial, (or others), as well as the support functions will have a better understanding of the maintenance activity impact and needs (like Procurement, etc.) (figure 43).

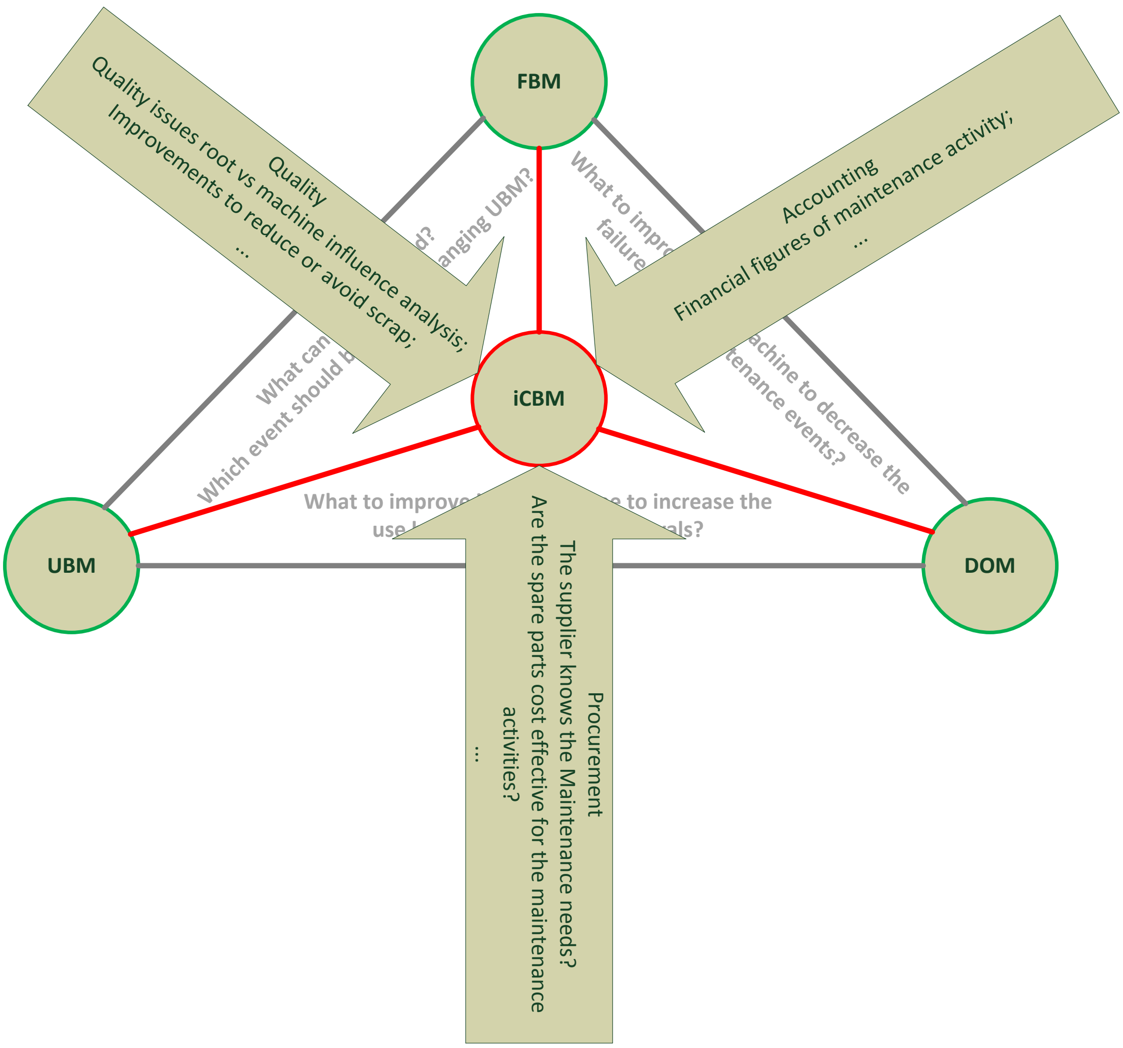


Figure 43 - iCBM support functions

4.3 The construction of the iCBM

As mentioned before, the iCBM team is based on the company's maintenance core teams. Therefore, the first step is to identify each group, mission and responsibilities in the role of maintenance. There are three distinct phases, as shown in the figure 44.

The phase 0 consists in the creation of a relationship between the existing groups and to define who and when will be available to participate in meetings and maintenance actions out of its regular maintenance team.

For this it might be needed to change time schedules, or to promote temporary movements within the teams. For the responsiveness of the complete maintenance personnel, it is desirable that each maintainer have the chance to participate in the iCBM team in a regular way.

The phase 1 is then ready to begin, bringing one or two participants of each maintenance team to the new iCBM team. This team meets regularly analysing the main maintenance topics, and needs and planning their activities, counting with the complete maintenance team members (even with all that are not present).

This phase might be longer and difficult than it appears as there is the need to have time to understand and to learn new approaches of maintenance by each maintainer, to change mind-sets and to get some training in new techniques and methods.

Then, the phase 2 should be promoted when the core team is totally developed, presenting the iCBM team and role to each partner function in a way that both iCBM and other function's representative can know how and when to initiate a group action or task.

4.4 Preconditions for an iCBM strategy set-up

The iCBM "maintenance" strategy is based in three aspects of the companies daily reality, which several time act as obstacle for changes in the proactive thought in maintenance:

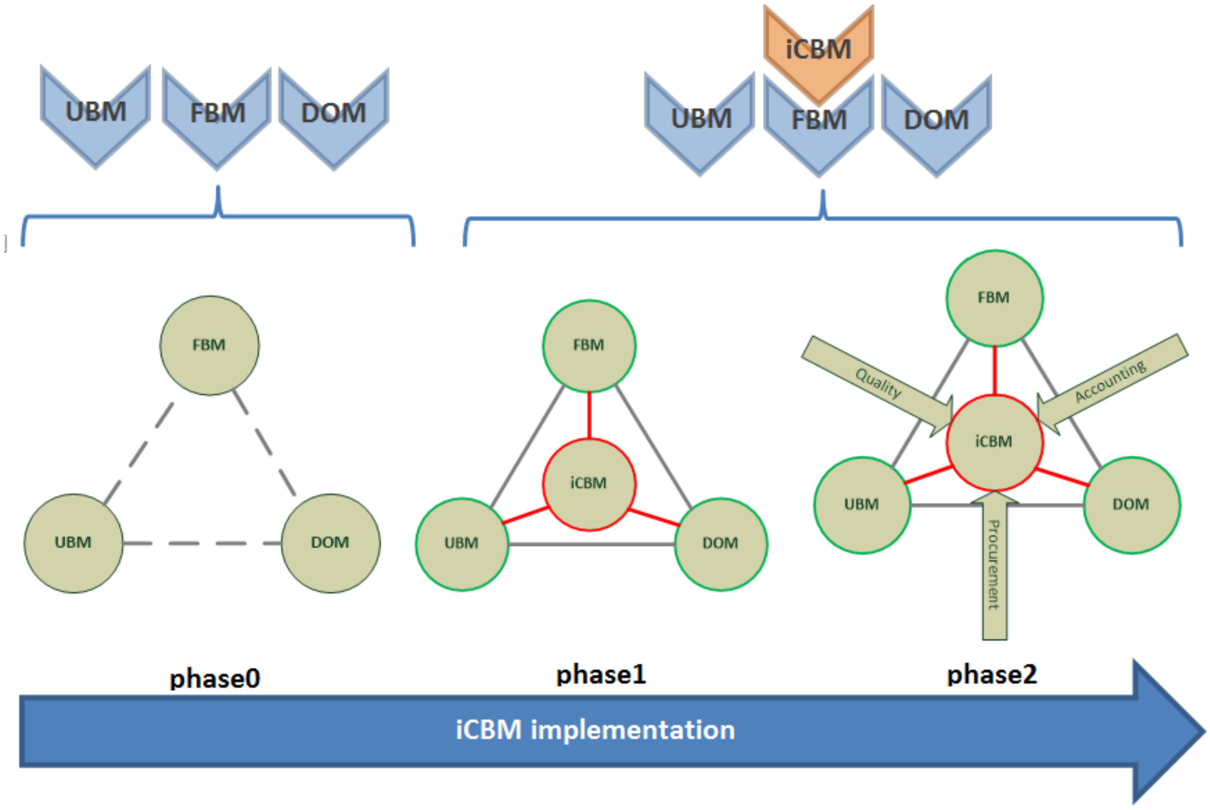


Figure 44 - CBM setting phases

- Breakdowns will ever happen (even in an outstanding predictive program, unexpected events will happen), and the management has to be "on the safe side". There are some failures which cannot be prevented by overhaul or preventive replacement action. The hazard rate of an item with this type of failure does not change with age (AHC Tsang, 1995);
- The machinery components start their way to failure at the very beginning they start to work, therefore is possible to estimate the probability that the equipment will fail in the specified interval, meaning that undertaken equipment care tasks regularly may avoid failures and extend lifetime (Swanson, 2001);
- Setting effective detection sensors is a dream of any maintenance manager, hindered by the difficulty of finding appropriate devices for all the machine's parts and by its high associated costs (Luxhoj, Riis, & Thorsteinsson, 1997).

Under this circumstances and considering that:

- Humans are themselves a complex system of sensors with the capability of making the correlation between the data coming in several ways with different experiences and contexts. Many of the potential failures can often be recognized by using the five human senses in order to continuously monitor the conditions of the machines (Jonsson, 2000);
- Inspecting, monitoring and planning on time is the only way to run against the failure in a cost-effective way (Eti et al., 2006);
- The exchange of knowledge between diverse practices and skills leads to a high level of proficiency (Boyer & McDermott, 1999);

The iCBM relies on the existence of at least more than one maintenance approach in the plant, and thus will includes members of:

- Corrective Maintenance (FBM) team members (mandatory);
- Preventive Maintenance (UBM) team members (mandatory, at least one permanent element, as leader);
- Engineering (DOM) team members (mandatory);
- Procurement Function (optional);
- Quality Function (optional);
- Accounting (optional);
- Other (optional).

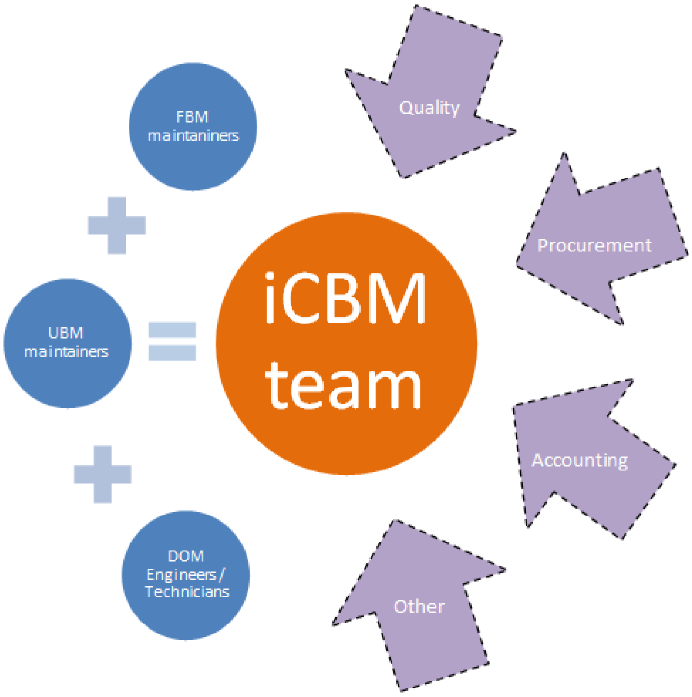


Figure 45: iCBM team members

4.5 iCBM organization, coordination and leadership

As mentioned before, the iCBM strategy takes body in a concurrent team mainly constituted with maintenance technicians. It is important that, in spite of possibly having several functions in the team, the workforce of an iCBM group are the maintainers as well as the decision making process shall be owned by them. Similarly each problem's ownership has to be accepted by the complete team (Eti et al., 2006). The importance of having other functions in the group is inherent to the fact of the difficult to access to important data as the financial impact of the current maintenance activity and some strategies, or for example to understand a certain effect in the product quality of certain failures, etc., which can be granted having one of these persons in the team as consultant.

Hence, the iCBM team has the mission of upgrading the maintenance goals to a level which is not limited anymore to having the machines back to run rapidly or replacing and overhauling just as its prescribed to by the UBM routines. Thereby it's very important the management involvement in the team, transmitting the major maintenance policies, in a way that the group might define the needed KPI's to be monitored: as the equipment uptime rate together with the costs control should be the basic

KPI's of the group, the management may require an especial attention the safety and accidents rate; or even with the scrap due to breakdown or equipment malfunction, etc..

To achieve these goals is very important that, at least in the case of the Corrective Maintenance team, all the maintainers could make part of the team, participating in an alternated way.

Assuming that the Corrective Maintenance technicians have contact with all the machines in a shorter period of time than the Preventive Maintenance (UBM) technicians, due to its type of activity, as well as that they would be present more often in the critical ones, each information and experience is very important to bring to the team. They are the "online" human sensors of the iCBM team.

Additionally, if possible, also an alternate participation of all the UBM maintainers might be positive, despite the fact that it might also be important to keep in the group the more expertise ones for each type of component or machinery.

The iCBM background in an maintenance policy is clearly under the Preventive Maintenance category, as it is any CBM strategy. However, this must not be the most significant factor in the time of choosing the coordinator and the team leader. It's advisable to carefully analyse, case by case before take a decision. If the coordination and leadership might be naturally delivered to the Preventive Maintenance coordination and leadership, the fact of the most part of the workforce possibly belong to the Corrective Maintenance team, might bring sensitive issues into the group in the daily business work and relations. Therefore depending on each case, this task might be deployed either by the Corrective Maintenance or the Preventive Maintenance coordinator. A thirdly part may also be a solution, although, this might mean additional costs to setup the team.

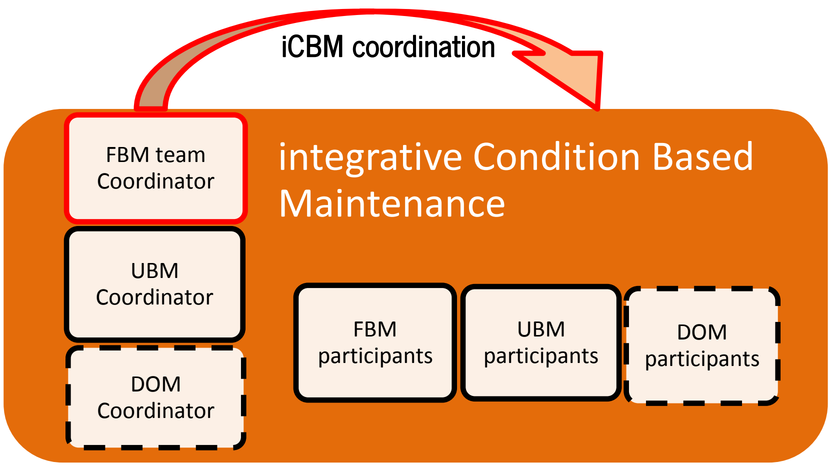


Figure 46: iCBM coordination

Regarding the team leadership, at least one member has to be permanent and it is important that this maintainer could come from the PM team. The main skills for this leadership are:

- to be able to plan, organise and re-organise task according the needs of the department, including unpredictable events;
- to be able to lead in a concurrent environment, possible having to face conflicts, and unstiffen a tough dialog or discussion;
- to have knowledge of at least the basic team working tools as workforce tasks, brainstorming, etc.;
- to have the best skills of leadership and team working.

The success of the team will only be possible with an appropriate training in root-cause analyses techniques and an organizational disciplines and procedures establishment guided by an appropriated leadership with a clear vision and mission (Eti et al., 2006).

4.6 The iCBM role and activities

Therefore the main tasks and activities of an iCBM team should be:

- to gather the information coming from the "sensors", i.e., from the FBM maintainers, registering the hotspots and alarms as critical and with high priority to plan a repair with the fastness as the case may require;
- to analyse the status of the defined KPI's for the maintenance activity, in order to achieve decision-making factors for the group activity (OEE, Costs, Scrap, etc.).
- to meet weekly with all the available members, inviting any consultant if required for any point of the agenda previously prepared;
- to schedule with Production the availability of the machine for a planned repair or inspection (mainly in the cases where the production stop is required).

These are the basic tasks defined for this model. However this plan has to be customized to the reality of each plant or organisation.

4.6.1 The iCBM meetings

The iCBM activity process has its core in the weekly iCBM meeting (figure 47 and Appendix II). The concurrent and collaborative environment of each iCBM meeting bring together the basic conditions to an adequate analysis and debate of the main maintenance issues of the moment, either the event-based one (coming from the breakdown reports, scrap reports or others) as well as the monitoring-based topics (coming from inspection routines, from the detection of the failure-based maintenance participants' experience, or others).

For the topic analysis, all the participants are invited to give their opinion, based on each expertise area. When possible (knowing the topics in advance), the iCBM coordinator has to previously invite the adequate participants to the meeting, for the success of the discussions (including support functions participants as Quality, Procurement or others).

4.6.2 The iCBM investigations

According the critical and complexity level of each topic, investigation actions might be planned. Those actions have extreme importance and should involve all the needed resources, including not only the adequate maintainers, as well as the equipment availability, any special conditions for the analysis (special production, recipes ...).

The investigation will be executed by the person or team designated by the iCBM coordinator during the meeting and its results will be given to him as soon as available. For the matter of this topic, the maintainer or team will be coordinated by the iCBM team. Task-forces actions might be defined to each team in order to develop investigations. In this case, each task-force action will be coordinated by each team leader, but the results and the management of each task-force objectives will continue under the coordination of the iCBM responsible.

4.6.3 The iCBM actions

All the actions with the purpose to answer to a specific topic will also be discussed by the complete team, taking into account its urgency, costs impact and the resource needs.

The action plan is established by the iCBM coordinator as well as its follow-up is ensure by him. The results of each action are to be discussed in the next iCBM meeting.

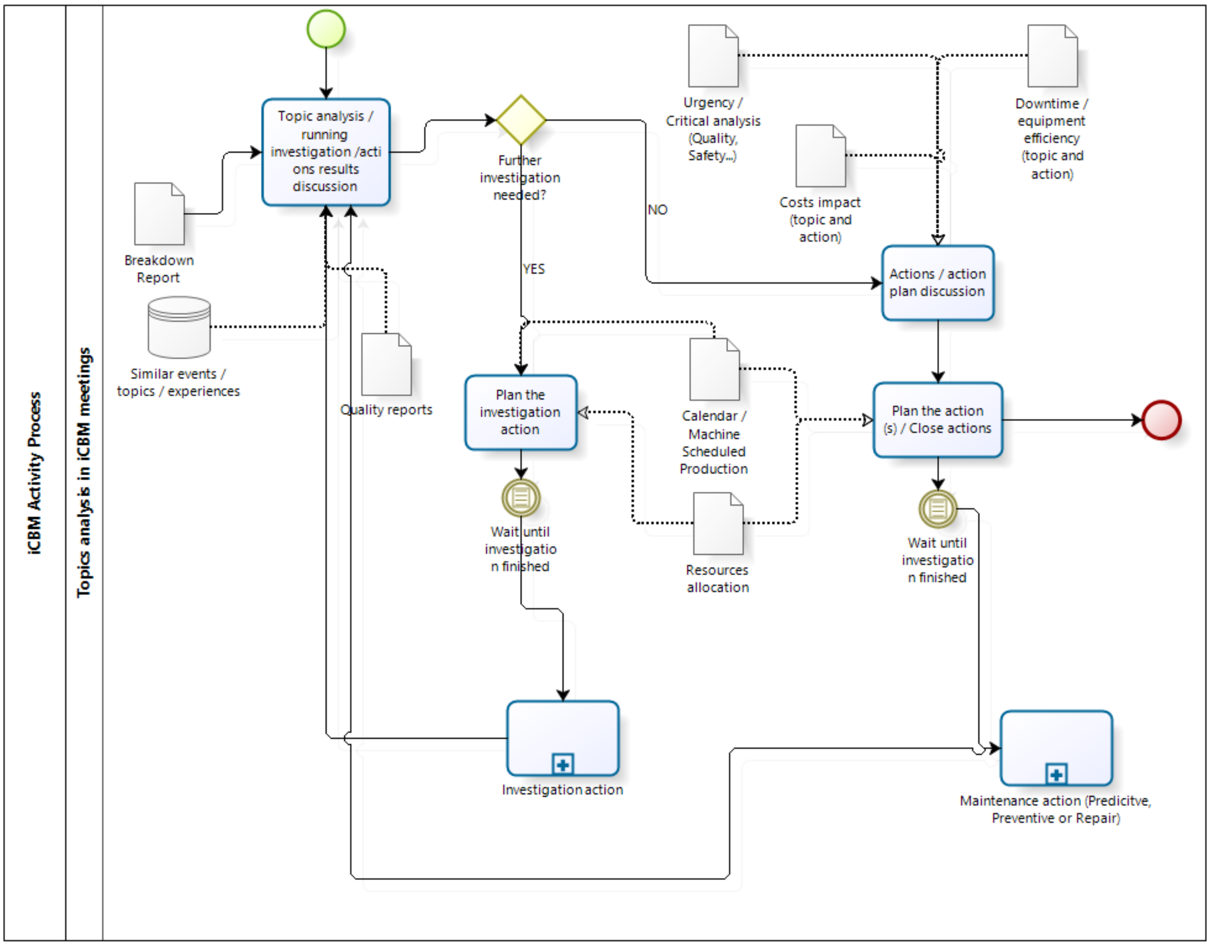


Figure 47 - iCBM activity process

4.7 Risks of an iCBM strategy set-up

The main risk for the set-up of a group as iCBM, resides in the high probability of conflicts. This probability will be as high as the level of sharing of responsibilities and machines among the groups.

The several teams (Corrective and Preventive Maintenance teams) usually share the responsibility of to maintain the machinery group in its best performance or at least to restore it to that state. As the teams share the same machines in different moments, this would allow that the work of every team is likely to be concluded (if not finished) or at least evaluated, by the next team in charge. It might be possible to hear rivalries as “they never finished the job” or “this was not fixed, just hidden”. Other claims may put in a field of battle the Preventive Maintenance team against the Corrective Maintenance one with the argument that "they are always pushing the problems to the next UBM planned activity instead of doing the repair when they could and should..."

These feelings don't fit to the environment needed to create this team. However this team might be a start to finish with some of these discussions...

Other risks that have to be considered are the motivation and the capability levels of the maintainers, used to work for several years in a context of "fire-fighting" in the reactive maintenance, to perform a different way of maintenance, where there is no breakdown order to answer, but problem to investigate till its root cause. The same resolutions as he is used to in FBM as simply to replace could not be the option... Identically difficult might have an UBM technician, used to follow a well-defined overhaul task, if given to an investigation task.

Last but not least, it might be that, in the first months of life, the iCBM have to lead with difficulties in planning their tasks and activities, and that the hours spent monitoring one machine or event gives the feeling of having idle and waste of resources.

It's very important but also difficult to be realized by all the maintenance organization that, the iCBM is, more than a team, an overall strategy that includes all the maintenance groups of the department in an integrative modus.

5. SET-UP OF AN ICBM STRATEGY AT CONTINENTAL MABOR ED2

5.1 The iCBM ED2 strategy

The iCBM strategy was defined by the Engineering Plant Management, together with the ED2 management and the Maintenance Coordinators. The guidelines for the team are based on the model described in the previous chapter, and the KPI's to consider in this case study were:

- The production equipment breakdown downtime rate;
- The activity costs.

In this approach, it was requested to have in focus mainly the equipment breakdown downtime rate reduction, thereby all the tasks were taking in account the evolution of this KPI. The activity costs were monitored and punctually taken into account for the decision-making, as second level priority.

5.2 The team structure

According the model, all the maintainers (both from Corrective and Preventive Maintenance) were considered to be members of these teams. In this company case, the Projects team were the DOM members of this iCBM team, as explained further on.

The first step was the model presentation and the preparation of each member in a way that any maintainer understands his role in this group. This was eventually the hardest work.

5.2.1 The FBM maintainer mission

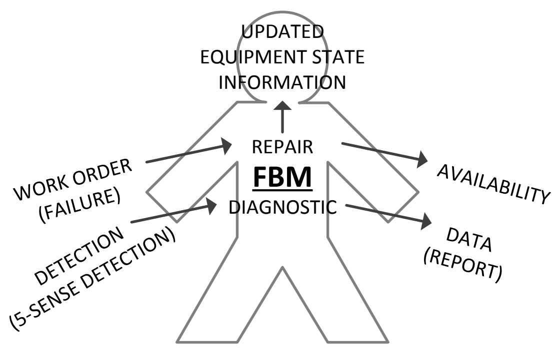


Figure 48: The FBM maintainter input/outputs

Due to its daily tasks, the FBM maintainer (figure 48) is the more up-to-date human sensor who can inform about the current state of the plant equipment.

Every time he is called to a repair action, he will have the chance to check the reasons behind the failure and to analyse the occurrence. Therefore, this maintainer will run the complete equipment group in a shorter time interval than the UBM maintainer. If by one hand this updating cycle is random, regulated by the occurrence of failures, for the other hand, the FBM maintainer is regularly present in the most machines of worst performance due to breakdown.

Moreover, when at the machine or equipment, he is able to detect other malfunctions or indication of malfunctions that probably he will not have the chance to solve at the moment, due to the pressure of having the equipment available for operation again.

5.2.2 The UBM maintainer mission

The UBM maintainer is probably the one who as a better knowledge of each part and the most detailed information about the requirements to extend the lifetime of a component. Thus, his function in the group becomes essential to cross-check with the FBM maintainer's experience about the exceptions to the prescribed behaviour of the components, as well as to confirm conclusions about symptoms or predicts brought to the analyses to the discussion table by the FBM or other member.

It is also important that the discussion and conclusions taken while working in the iCBM team, can have impact in the future UBM activities, both in operational and tactical plans.

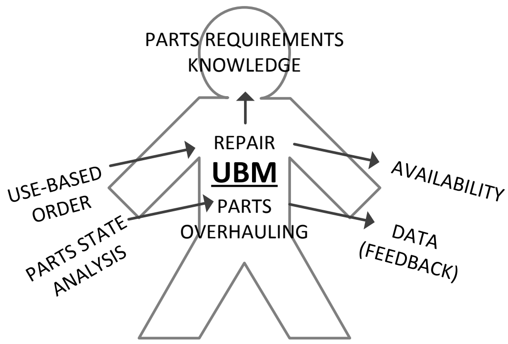


Figure 49: The UBM maintainter input/outputs

5.2.3 The Projects member's mission

Other existing maintenance teams have also place in the team, whenever they exist in the plant, such as DOM maintainers or others. In the ED2 case, the Projects team, an engineering group, constitutes the DOM members included in the iCBM team, with the purpose of making possible a deeply analysis of the machine's concept, in order to reduce or eliminate the problems since the design phase of that machine. Usually involved in this machine development stages, these participants get a better understanding of the maintainability of each equipment or machine within this iCBM activities, thus being capable to participate in machine design reviews, as well as to influence the design of new units (figure 50).

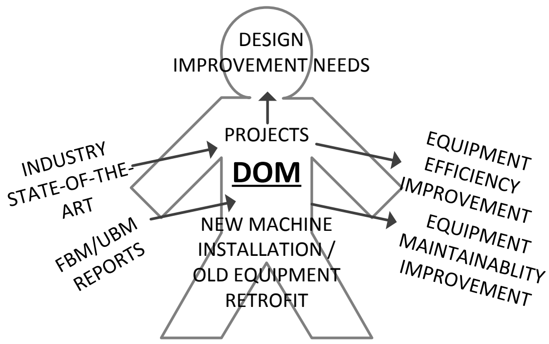


Figure 50 - The DOM maintainter input/outputs

The ED2 iCBM team structure was then defined integrating this these three group of maintainers, with the aim of having a regular analysis of the maintenance activities and its major problems, taking into account the strategic goals of the department, namely the downtime rate and costs control, among others like quality and safety.

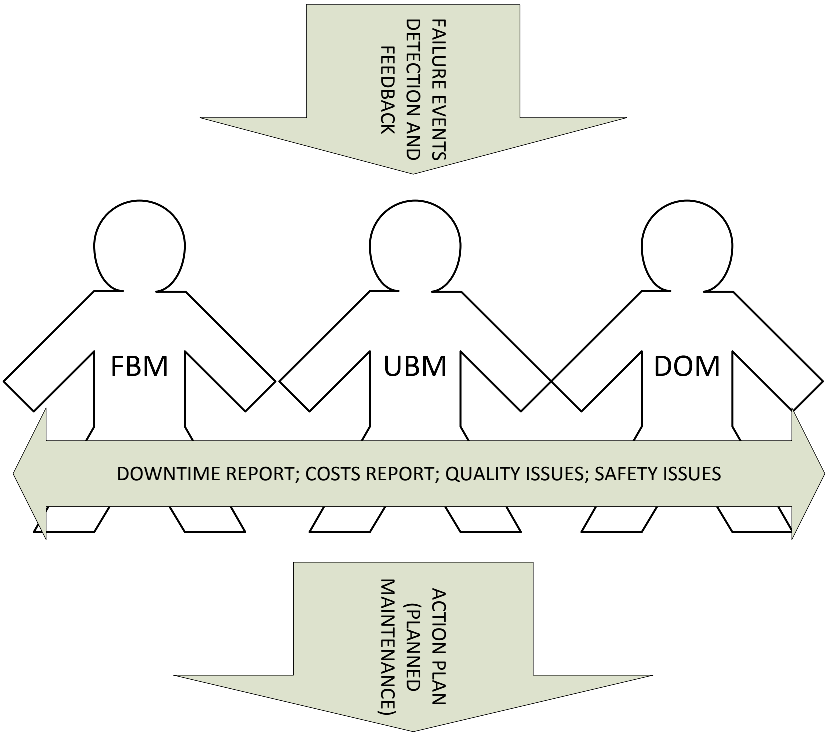


Figure 51: iCBM workflow

5.3 Changes in the ED2 to build the iCBM team

From tem Preventive Maintenance side, the MTC team as a fixed group has finished and its leader, as a member of the Preventive Maintenance team, becomes the leader of the new iCBM team. Together with the other technician (this team had two members) these two Preventive Maintenance members are the permanent members of the iCBM team.

To achieve the goal of to include the Corrective Maintenance team members, the work allocation of the weekend shifts maintainers has changed from the reinforcement of the week FBM teams to the structure of this new team. The number of technicians in the week group was possible to keep only because it was previously planned to increase the MTC team with three people. The new people were divided by the teams A, B and C, totalling now six fixed maintainers as the teams D and E.

The new allocation table had to be completely reconstructed, in a way that all the Corrective Maintenance members had the chance to participate in the team activities, including the week team members, keeping those teams with six technicians. Therefore, the previous allocation table (see table 3 in the chapter 3), has evolved to a new one (table 4).

Table 4: New resources allocation table

SEM 41		SEG		TER		QUA		QUI		SEX	SAB/DOM
M. Prev.	7-15h			D5		D5		D6		D6	
M. Corret.	8-14h	6B		6B		6B		6B		6B	6E (8-19h) 6D (19-6h) 6E (6-14h) 6D (14-0h) 6E (0-8h)
	14-16h	5B	E4	5B	E4	5B	E3	5B	E3		
	16-22h	5C		5C		5C		5C		6C	
	22-24h	6C		6C		6C		6C			
	0-8h	6A		6A		6A		6A		6A	
M. Condic.	8-16h			D1		D1		E2		E2	
	14-16h	1B	E5	1B	E5	1B	E6	1B	E6		
	16-22h	1C	E1	1C	D4 E1	1C		1C	D3 D2	D3 D2	

SEM 42		SEG		TER		QUA		QUI		SEX	SAB/DOM
M. Prev.	7-15h			E5		E5		E6		E6	
M. Corret.	8-14h	6C		6C		6C		6C		6C	6D (8-19h) 6E (19-6h) 6D (6-14h) 6E (14-0h) 6D (0-8h)
	14-16h	5C	D4	6C		5C	D3	5C	D3		
	16-22h	5A		6A		5A		5A		6A	
	22-24h	6A		6A		6A		6A			
	0-8h	6B		6B		6B		6B		6B	
M. Condic.	8-16h			E1		E1		D2		D2	
	14-16h	1C	D5		D5	1C	D6	1C	D6		
	16-22h	1A	D1		E2 D1	1A	E2	1A	E3 E4	E3 E4	

SEM 43		SEG		TER		QUA		QUI		SEX	SAB/DOM
M. Prev.	7-15h			D5		D5		D6		D6	
M. Corret.	8-14h	6A		6A		6A		6A		6A	6E (8-19h) 6D (19-6h) 6E (6-14h) 6D (14-0h) 6E (0-8h)
	14-16h	5A	E1	5A	E1	5A	E4	5A	E4		
	16-22h	5B		5B		5B		5B		6B	
	22-24h	6B		6B		6B		6B			
	0-8h	6C		6C		6C		6C		6C	
M. Condic.	8-16h			D2		D2		E3		E3	
	14-16h	1A	E5	1A	E5	1A	E6	1A	E6		
	16-22h	1B	E2	1B	D1 E2	1B	D1	1B	D4 D3	D3	

SEM 44		SEG		TER		QUA		QUI		SEX	SAB/DOM
M. Prev.	7-15h			E5		E5		E6		E6	
M. Corret.	8-14h	6B		6B		6B		6B		6B	6E (8-19h) 6D (19-6h) 6E (6-14h) 6D (14-0h) 6E (0-8h)
	14-16h	5B	D1	5B	D1	5B	D4	6B			
	16-22h	5C		5C		5C		6C		6C	
	22-24h	6C		6C		6C		6C			
	0-8h	6A		6A		6A		6A		6A	
M. Condic.	8-16h			E2		E2		D3		D3	
	14-16h	1B	D5	1B	D5	1B	D6		D6		
	16-22h	1C	D2	1C	E3 D2	1C	E3		E4 E1	E4 E1	

The new allocation table was an opportunity to create motivation in the team. For one hand, because it was taken the chance of setting consecutive days for the two obligatory week days of work of each weekend team member, which allows to set equally wider consecutive resting days. It's important to note that the amounts of consecutive hours in the weekend shifts are quite aggressive. It was similarly saved the Monday morning, or it would force that some technicians whom had leaved the work at midnight, had to start to work eight hours after.

The creation of this new allocation table was done using linear programming methods available in the MsExcel worksheet "Solver" add-in, as it can be shown in the figure 52.

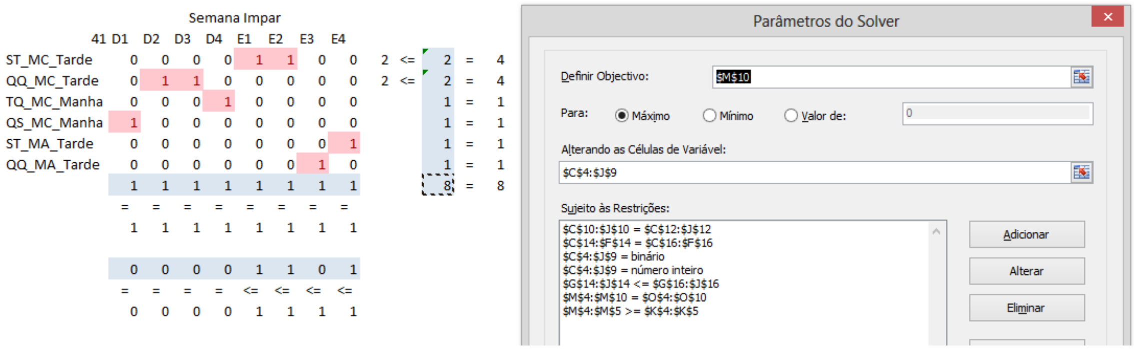


Figure 52: The building of a new allocation table

In this way the structure of the team was built, having as final result:

- two members coming from the Preventive Maintenance teams;
- up to four members coming from the Corrective Maintenance teams;
- (occasionally) members from the Projects team;
- the Corrective and Preventive Maintenance coordinators, as well as the Projects team coordinator.

The coordination of this new team is done by the Corrective Maintenance coordinator with a partnership with the Preventive Maintenance and the Projects team coordinators.

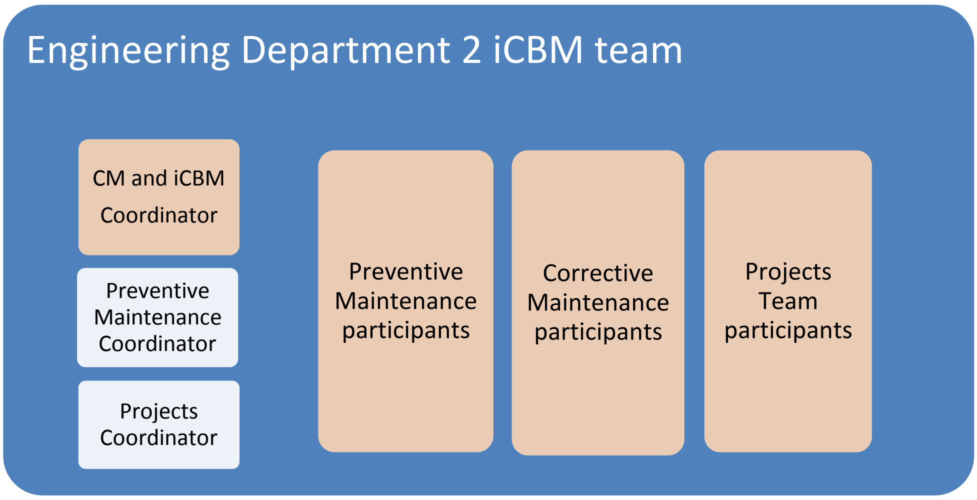


Figure 53: iCBM coordination scheme

5.4 The iCBM team activities and responsibilities

Once define the iCBM team, as described above, the next step was to define the team activities and responsibilities.

For the purpose of this project, it was chosen on machine group where it was given the main focus of the team, according a KPI criteria based on the downtime rate. Therefore, it was selected the APEX machines, as it was identified an urgent need in decreasing the downtime due to breakdown of these twelve machines.

Thereby, the team start with:

- A deeply analysis of the Corrective Maintenance activity reports in these machines;

- To collect all the relevant data regarding the APEX machine performance, critical breakdowns, repetitive failures and its operating difficulties;
- To monitor the Monthly Breakdown Report.

For the action plan, the team defined:

- A weekly meeting which included all the members coming from the FBM and UBM teams allocated to this team in the meeting day, as well as the coordinators of the Corrective and Preventive Maintenance and the Projects teams.
- The debate of the critical points according the several experiences of the team members;
- To gather the information coming from the "sensors", i.e., from the FBM maintainers, registering the hotspots and alarms as critical and with high priority to plan a repair with the fastness as the case may require;
- The setup of strategic taskforce actions for each critical point, shared by the team members, with follow-up in the weekly meetings;
- To analyse the status of the defined KPI's for the maintenance activity, in order to achieve decision-making factors for the group activity;
- To schedule several overhauling and repair actions, with the production management agreement, in order to avoid as much as possible, the disruption of the production plans.
- Discussion about the implementation of monitoring systems, bringing to the office level relevant data regarding the machine components status;
- Discussion about the improvement of the breakdown report system and training to the teams.

Besides the weekly meeting, the iCBM team members start every day with a short briefing (up to 30 minutes) to analyse the previous day FBM report, as well as any other relevant event or running task status.

As a concurrent and collaborative team, iCBM had the need to create a decision-making model in order to guide the analysis and discussion of the actions to be done for each identified problem. Therefore, the diagram of processes and events was mounted in order to support each discussion and a final decision (figure 54).

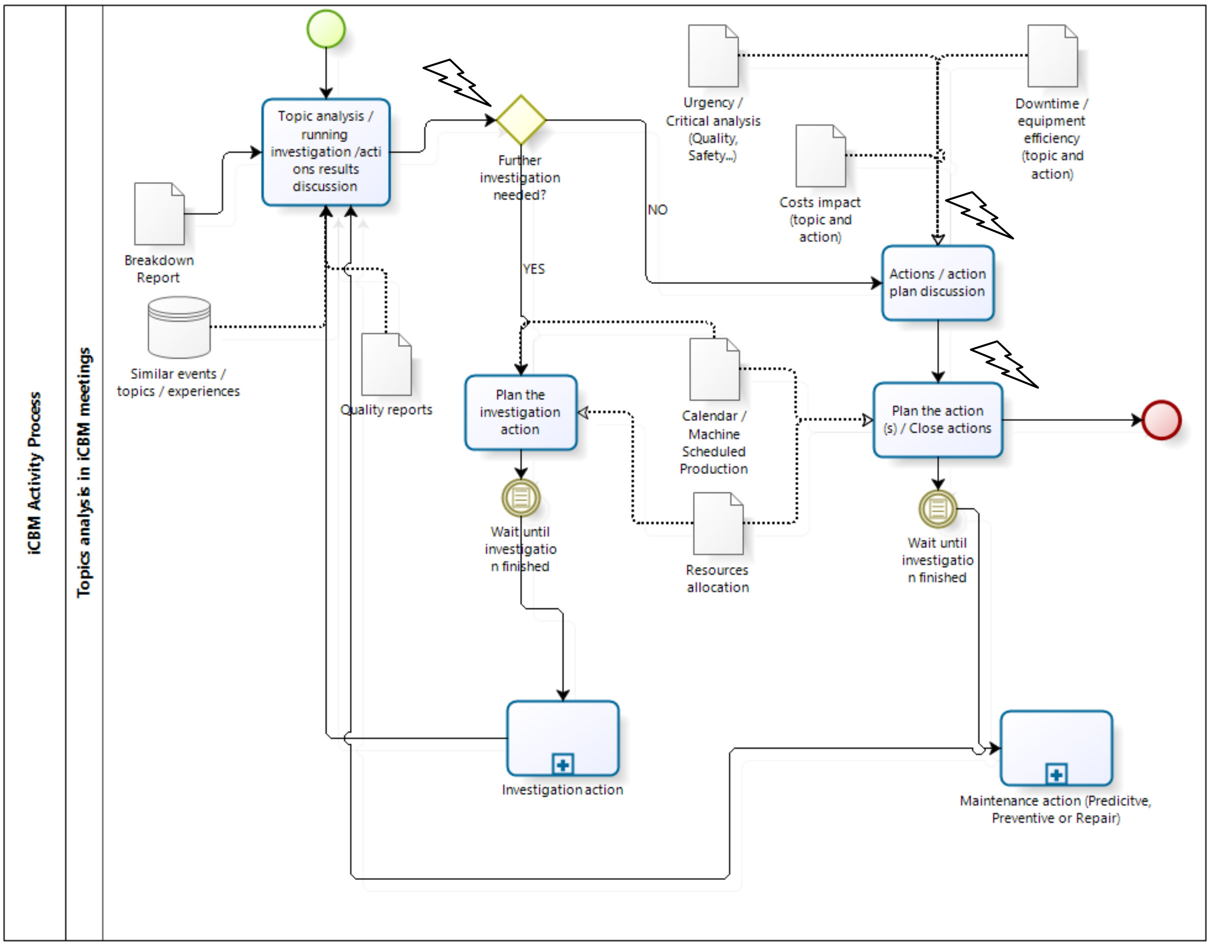


Figure 54: The iCBM decision diagram

An event under the analysis of the iCBM team might have several initiators:

- A critical event or the threat of a critical event detected by a maintainer or an operator;
- A quality issue required to be investigated whether might be related to an equipment failure or malfunction;
- A safety risk detected by any equipment intervenient or responsible, or even any occurred accident;
- The need of improve the maintainability of an equipment, which could lead to reduced repair times and thus to an increase in its availability;
- Regular failures without root-cause detection done.

These initiators have any event associated:

- A failure, quality issue or accident occurrence;

- A breakdown report, operator or maintainer detection or feedback;
- Others.

The carefully analysis is made integrating all the actors that might have the experience and influence in the event under investigation. All the knowledge is considered and important for the definition of the adequate action plan.

If required, further investigations are planned, including all the needed resources (human and others). These investigations might also include the machine operation observation, test cases among others. This step might be critical according:

- The urgency of an action;
- The risks of some test cases (scrap, equipment damages, others).

After a consensus regarding the action, the action plan is developed according:

- The requirements of the action (equipment downtime, spare parts replacement or overhaul and its related costs, specific skilled personnel allocation);
- The requirements of the event (is it critical and urgent by any quality issue or other? Is it possible to include in any scheduled maintenance action already foreseen for this machine, as UBM?)

Finally the action is planned and followed by the group, turning to the group so many times as needed until eliminate or control the initial problem.

6. iCBM IMPLEMENTATION RESULTS AT CONTINENTAL MABOR

6.1 The results of reducing unplanned repairs towards a proactive maintenance

Before the iCBM implementation, the unbalance between the Corrective and the Preventive Maintenance activity was sharply inclined to the side of the corrective actions as it is described in the allocation table below (table 5).

Table 5: Initial reactive-focused maintenance versus proactive focused maintenance allocation table

	Corrective Maintenance teams					Preventive Maintenance teams		
	Team A	Team B	Team C	Team D	Team E	PREP Team	TBM Team	MTC team
Electrical technicians	2	2	2	3	3	2	1	1
Mechanical technicias	3	3	3	3	3	5	6	1
Total elements	5	5	5	6	6	7	7	2
Tech in FBM tasks	5	5	5	6	6	2	2	1
Tech in UBM tasks	0	0	0	2	2	5	6	1
Electricians FBM hours/month	320	320	320	640	640	0	0	0
Mechanics FBM hours/month	480	480	480	192	192	0	0	0
Electricians UBM hours/month	0	0	0	0	0	320	160	160
Mechanics UBM hours/month	0	0	0	128	128	800	960	160
FBM hours/month	800	800	800	832	832	0	0	0
UBM hours/month	0	0	0	128	128	1120	1120	320

With a total of 43 technicians, the Corrective Maintenance teams had in total 27 members and the Preventive Maintenance teams had 16 members.

Considering the monthly hours spent in each maintenance strategy, the FBM work was counting total 4064 hours of work, while the preventive maintenance task (most part of them use-based maintenance tasks), was counting 2816 hours.

Table 6: intial maintenance activities distribution table

	Before iCBM
Available hrs/month	6880
Total FBM hrs/month	4064
Total PM (UBM+CBM) hrs/month	2816
% FBM time	59,1%
% PM (UBM) time	40,9%

The presented distribution show that the main strategy of the department was still in the repair actions, as nearly 60% of the maintenance activity was failure-based oriented.

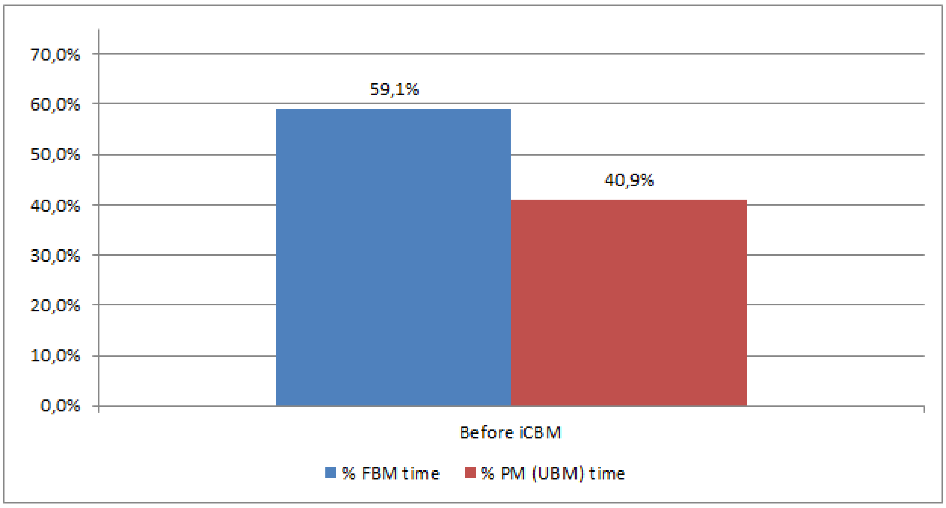


Figure 55: initial maintenance activities distribution graph

This distribution was due to the fact that all the electricians working in the corrective maintenance in the weekend shifts were also 100% dedicated to the FBM approach during their week work. By the other hand, the mechanics weekend members of the corrective maintenance teams were being integrated in the UBM teams during the week.

With the iCBM implementation, this situation has started its way in the opposite sense.

Not in the scope of this project, the ED2 hired three new electricians initially designed to engross the UBM maintenance teams. However, these three new elements completed each one of the FBM teams, releasing completely the weekend FBM members for the iCBM integration task, which also included to create opportunities for the week FBM members participation in the this new team.

Therefore, with the new iCBM allocation table, all the maintainers are work-centers which are no longer dedicate to a single approach but that are more and more driven to this new proactive approach.

Table 7: Final reactive-focused maintenance versus proactive focused maintenance allocation table

	Corrective Maintenance teams					Preventive Maintenance teams		
	Team A	Team B	Team C	Team D	Team E	PREP Team	TBM Team	iCBM team*
Electrical technicians	3	3	3	3	3	2	1	1
Mechanical technicias	3	3	3	3	3	5	6	1
Total elements	6	6	6	6	6	7	7	2
Tech in FBM tasks	6	6	6	6	6	2	2	0
Tech in UBM tasks	0	0	0	2	2	5	6	0
Tech in CBM tasks	3	3	3	6	6	0	0	2
Electricians FBM hours/month	352	352	352	384	384	0	0	0
Mechanics FBM hours/month	480	480	480	192	192	0	0	0
Electricians UBM hours/month	0	0	0	0	0	320	160	0
Mechanics UBM hours/month	0	0	0	64	64	800	960	0
Electricians CBM hours/month	128	128	128	256	256	0	0	160
Mechanics CBM hours/month	0	0	0	64	64	0	0	160
FBM hours/month	832	832	832	576	576	0	0	0
UBM hours/month	0	0	0	64	64	1120	1120	0
CBM hours/month	128	128	128	320	320	0	0	320

(*) Note: during the implementation of this model, three new maintainers were included in the corrective maintenance teams A, B and C (the week maintenance shifts teams). Therefore the increase in the maintenance available hours in the table below.

The final result in terms of maintenance activity distribution was a slightly inversion of the tendency in favour of the preventive and predictive maintenance routines.

Table 8: final maintenance activities distribution table

	After iCBM
Available hrs/month	7360
Total FBM hrs/month	3648
Total PM (UBM+CBM) hrs/month	3712
% FBM time	49,6%
% PM (UBM) time	50,4%

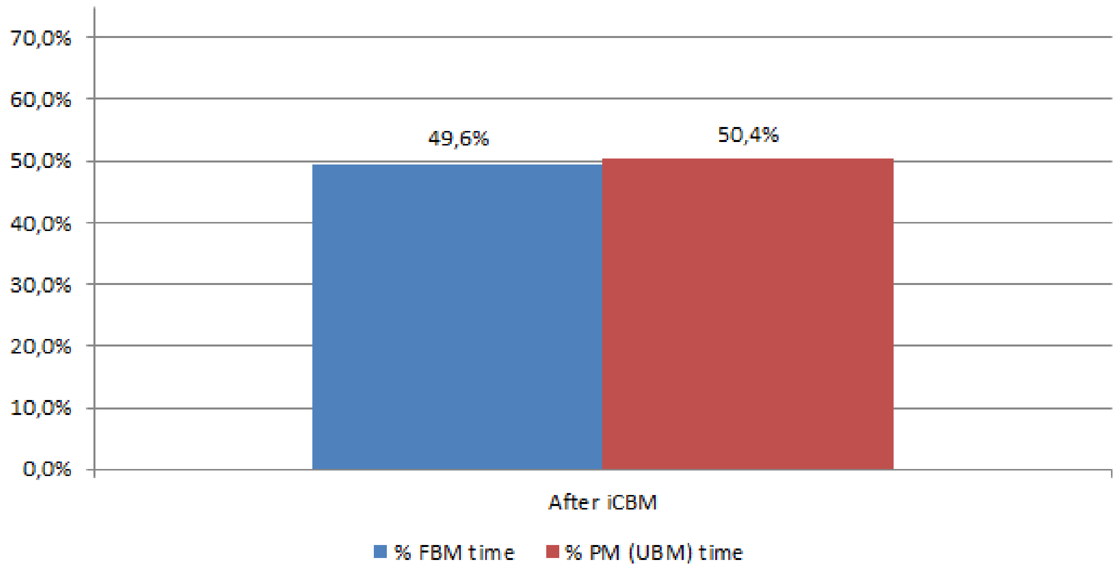


Figure 56: Final maintenance activites distribution graph

The positive effects of this change had to be tested against the maintenance strategic goals results. Therefore, it was chosen the lowest performance machine group to test the approach: the Apex machines.

6.2 The results of the iCBM approach in the Apex machines group

6.2.1 The Apex machines initial state

The Apex machines are the equipment where the apex strip is mounted over the bead of the tire. These machines comprise a wide range of process such as extrusion, cooling or heating, slitting, cutting and shaping by means of a pneumatic drum.

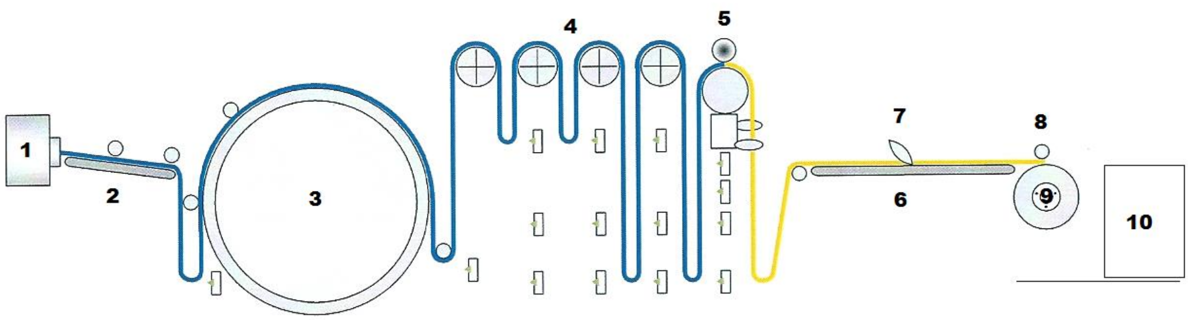


Figure 57: Apex machine diagram

The main components of an Apex machine are:

1 – Extruder with metal detector at entry;

2 – Conveyor;

3 – Cooling/heating drum;

4 – Loop rolls;

5 – Slitter;

6 – Transport table;

7 – Cutting blades;

8 – Apex applicator;

9 – Pneumatic drum;

10 – Beads car.

During the last year, the downtime due to breakdown of these machines had seriously become critical, as shown in the figure 58, with an increasing tendency. The vertical green bar (¦) indicates the start of the iCBM implementation.

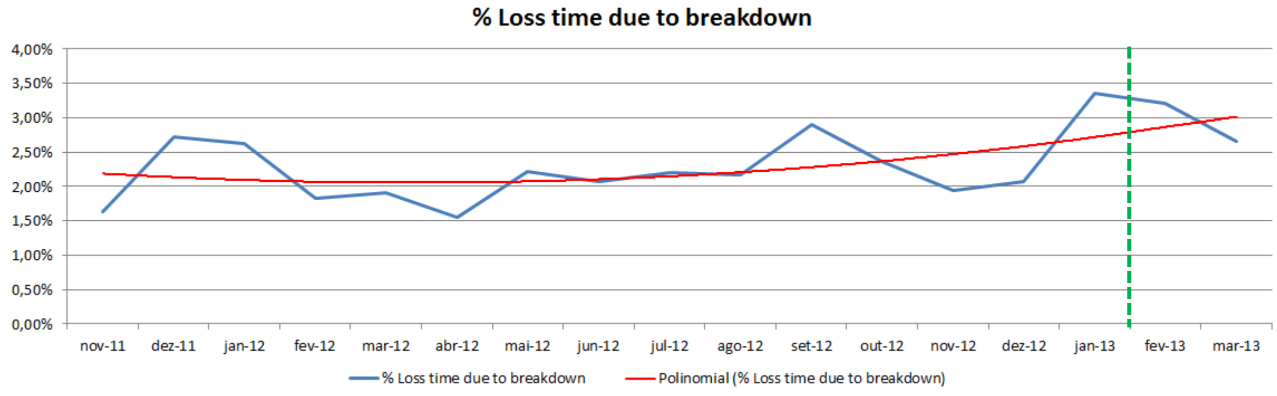


Figure 58: Apex loss time percentage due to breakdown before iCBM tasks

The KPI: loss time due to breakdown

The breakdown loss time indicator is the percentage of time that shows the relation between the period of time that a certain production equipment is unavailable due to breakdown, comparing to the planning working time for that equipment.

Therefore, this KPI is calculated:

$$\text{Loss time due to breakdown (\%)} = \frac{Mechanical\ breakdown\ time + Electrical\ breakdown\ time}{Planned\ working\ time} \times 100$$

The Apex loss time table per machine, from March to September 2012, before iCBM implementation, can be seen in the table below:

Table 9: loss time due to breakdown per Apex before iCBM

Bead 2012	Vorking Time	Mech Breakdown	Elect. Breakdown	% Loss due to Break.	Horas Trabalhadas	TP total Avaria
22A01	10100901,06	513492,6997	243152,1793	7,49%	2805:48	210:11
22A02	9696163,962	507162,3873	198720,7861	7,28%	2693:23	196:5
22A03	11460529,04	124051,2449	96847,77399	1,93%	3183:29	61:22
22A04	10925234,06	237715,0889	87466,60098	2,98%	3034:47	90:20
22A05	11010285,13	186596,9961	118156,315	2,77%	3058:25	84:39
22A06	9899538,304	251514,9329	341837,062	5,99%	2749:52	164:49
22A07	9667855,957	245743,445	323854,178	5,89%	2685:31	158:13
22A08	10877812,08	112731,0561	142830,708	2,35%	3021:37	70:59
22A09	10459992,28	204217,114	259280,603	4,43%	2905:33	128:45
22A10	10116112,81	259343,2251	184418,532	4,39%	2810:2	123:16
22A11	3031214,808	102748,9431	148441,7121	8,29%	842:0	69:47
22A12	9057071,467	126989,166	133989,472	2,88%	2515:51	72:30
Bead % Total loss				4,43%		

As iCBM focused machine group, the APEX machines where inspected, monitored by each maintainer during their normal daily work and also during the time each technician was allocated to the iCBM activities.

FBM reports were analysed and discussed in detail and several actions were planned as it might be seen in the Appendix 1.

The results so far obtained show a tendency inversion of the breakdown loss time, as well as its steadying (figure 59). The vertical green bar (¦) indicates the start of the iCBM implementation.

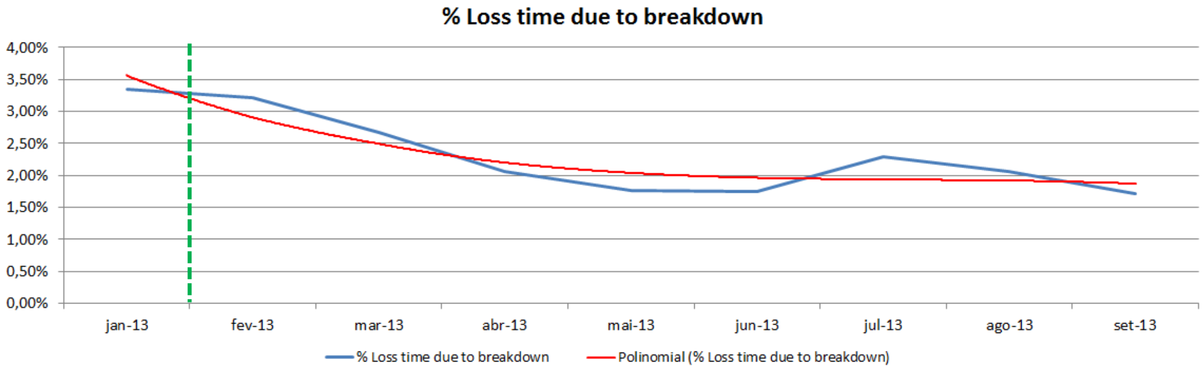


Figure 59: Apex loss time percentage due to breakdown after iCBM tasks

The Apex loss time table per machine, from March to September 2013, after iCBM implementation, can be seen in the table 10.

Table 10: loss time due to breakdown per Apex after iCBM

Bead 2013	Vorking Time	Mech Breakdown	Elect. Breakdown	% Loss due to Break.	Horas Trabalhadas	TP total Avaria
22A01	14475360,61	232005,661	111571,217	2,37%	4020:56	95:26
22A02	14280238,47	178895,154	122596,719	2,11%	3966:44	83:45
22A03	14327371,2	106483,962	55501,307	1,13%	3979:50	44:60
22A04	14403604,75	172075,729	94009,139	1,85%	4001:0	73:55
22A05	14486126,71	119453,613	82599,425	1,39%	4023:55	56:8
22A06	14226746,06	193466,981	171231,529	2,56%	3951:52	101:18
22A07	13862290,29	156192,971	140062,274	2,14%	3850:38	82:18
22A08	14562880,05	88797,672	67859,018	1,08%	4045:15	43:31
22A09	14714047,88	143932,009	227640,854	2,53%	4087:14	103:13
22A10	14590855,3	112052,795	104605,917	1,48%	4053:1	60:11
22A11	13324322,23	176268,812	168284,815	2,59%	3701:12	95:43
22A12	14827085,52	150149,653	109254,662	1,75%	4118:38	72:3
Bead % Total loss				**1,91%**		

When considering the amount of time spent to restore the machine in a state that it can perform its function was significantly reduced. In the figure 60, the number of repair work orders by machine reported in the CMMS (SAP PM) during the last year (before iCBM) the red bars, comparing to the repair work orders by machine reported in same CMMS during 2013. Both periods comprehends the same months (from January to September), in a way that data can be comparable (both periods includes the plant shutdowns, summer or winter effect, etc.).

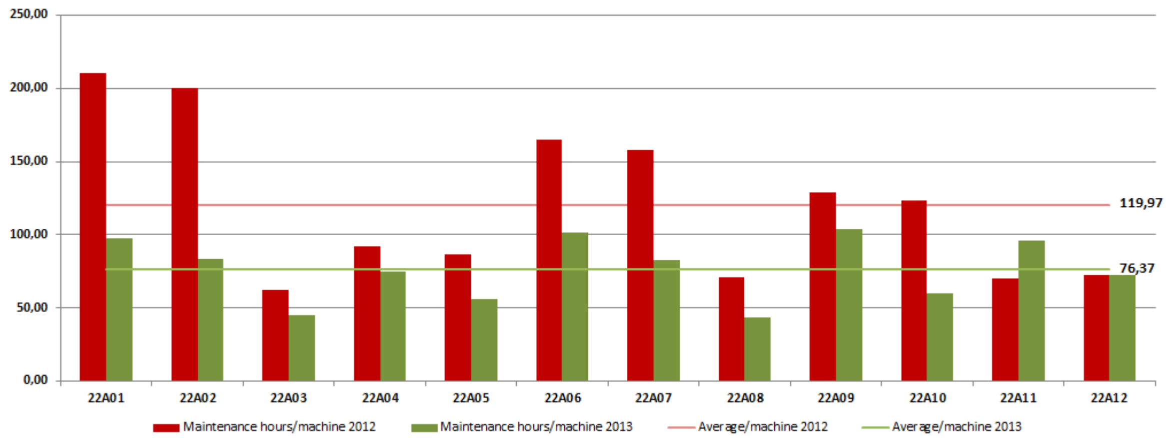


Figure 60: FBM work orders by machine comparison, before and after iCBM

It might be important to note the critical case of APEX11, which was stopped for long periods during the last year due to its lower performance. After the iCBM tasks in this machine, is possible to see that, although with an increased amount of corrective maintenance work orders, the performance of this machine was highly increased as its downtime rate decreased from 8,29% to 2,59% (figure 63).

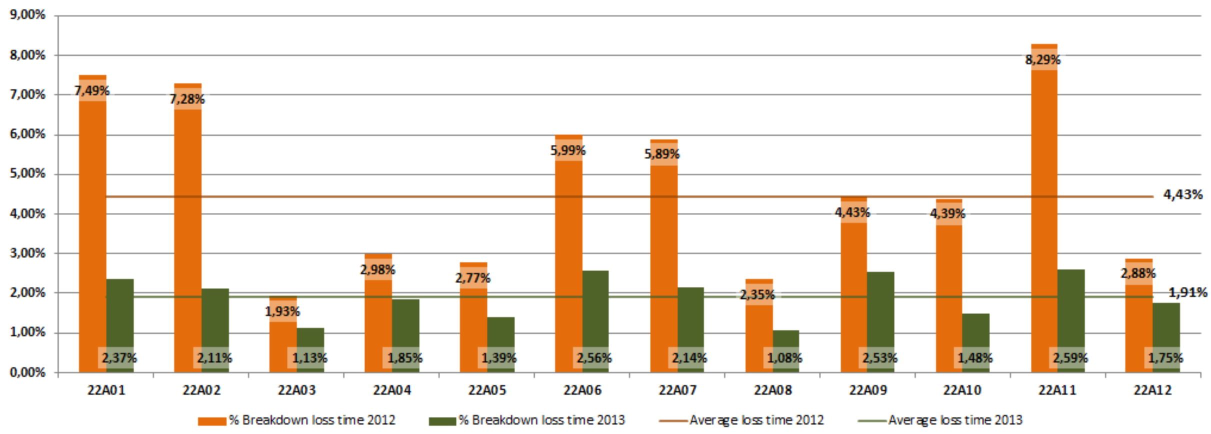


Figure 61: Breakdown loss time by machine, before and after iCBM

The evolution along the time of the iCBM implementation in the APEX machines group resulted in a relevant decrease of the downtime due to breakdown.

Within the same period as described before (from January to September) 2013 (green bars) shown an expressively improvement on these machines availability when comparing to 2012 (orange bars), as shown in the figure 61.

The overall result of the Apex machine group, since the beginning of the year expresses a conclusive decrease in the downtime rate.

7. CONCLUSIONS

7.1 The impact of Concurrent Engineering in the maintenance strategy

As the result of a change in the main strategy of the ED2 department, with the implementation of this Integrative Condition-Based Maintenance model, the machinery availability of the chosen machines group, in which the team focused their activities, has increased significantly.

The machine group selected for this project turned from a critical performance level to an expressively improved one, with high steadiness. Before the iCBM implementation, the daily rule on these machines was the failure-based maintenance tasks, mirrored in the downtime rates showed in the previous chapters. After the iCBM implementation, as consequence of this activity, the rule become nearly zero daily failure-based activity, and smaller interventions in the failure occurrences. This decreasing in the overall mean time to repair – e (MTTR), as well as the increase of the mean time between failures (MTBF) – both estimated –, states the absence of catastrophic failures, conversely to the past.

Having a concurrent approach as main strategy in the maintenance activity was the first step to start the changing of mind-sets and of the maintenance paradigm itself in the department. From a reaction-focused to a proactive-focused attitude, maintenance activities become to be possible to come up more in a tone of planning than the always undesired fire-fighting.

Using integration of all the existing players, stimulating the experience of each maintainer, bringing each piece of know-how as a piece of a puzzle, allowed to smoothly give the first steps of a big change, circumventing any risk of creating disturbances that jeopardize the maintenance activity itself as well as the necessary continuous support to production.

The iCBM activity settled in the team members the mind-set of the adequate-maintenance planning, in opposition to previous methods which, whether they promote excessive frequency or under maintenance, It continuously resulted in decreased equipment availability. Therefore, the results of this adequate-maintenance planning brought about more uptime to the production's machinery.

Regarding the maintainer's motivation, the iCBM created an opportunity to discuss, to analyse, and therefore to learn. This has created a motivating workplace environment, where each maintainer has the chance to let grow his expertise and to learn and practice new abilities.

7.2 Suggestions for further researches

The test case of this project was focused on the uptime KPI. However, the presented potential for the model suggests positive results when integrating costs, scrap and quality objectives within the iCBM goals.

Further research may, thereby, to investigate the complementary dimensions of this model, with special focus in the support functions interaction, as Quality, Accounting among others.

As a model which compromises the integration of a company's strategic objectives in the Maintenance activity, it would also important to measure the impact of the iCBM application in the contribution of this function for the organization's results (in costs, quality, production figures, etc.).

As a proposed model of the application of Concurrent Engineering principles in a Maintenance strategy design, it would be important to test it under different environment and in a wide range of maintenance policies. Thus, further researches could investigate the application of the iCBM model in organizations where Maintenance has different a configuration and approach than the test case of this work.

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APENDIX I – APEX MACHINES ICBM ACTIVITIES

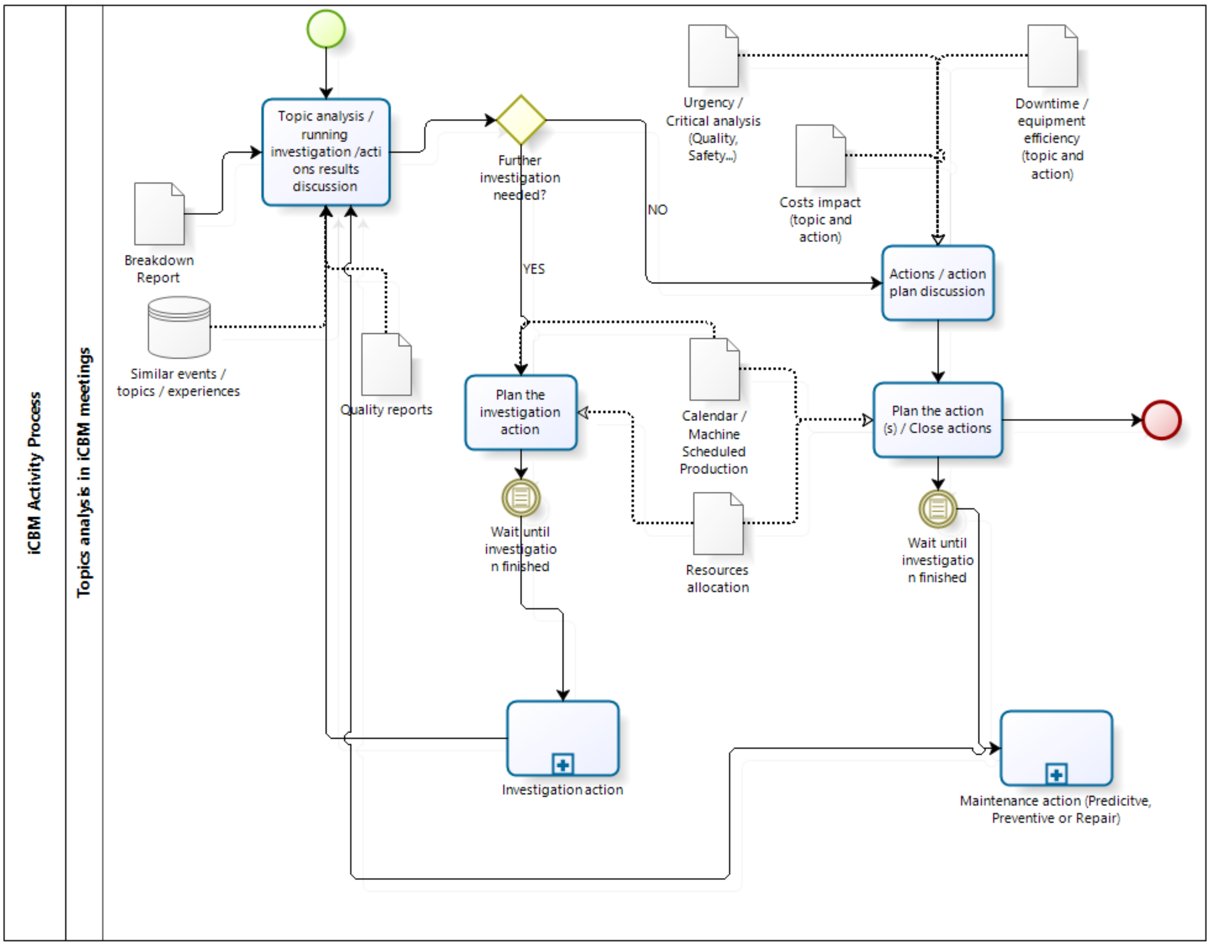
Loc.instalação	Descrição	Denominação	Dt.criação
8200-PRE-APX	M.C. -Verificar funcionamento Det. Metal		09-01-2013
8200-PRE-APX-APX11	Substituição das barreiras de segurança	Sistema de Segurança	11-01-2013
8200-PRE-APX-APX11	M.C. -Recolocação barreira segurança ver	Sistema de Segurança	15-01-2013
8200-PRE-APX-APX04	M.C. -Ajuste altura tabuleiro	Tabuleiro	16-01-2013
8200-PRE-APX-APX05	M.C. -Ajuste altura tabuleiro	Transportador	22-01-2013
8200-PRE-APX-APX07	M.C. -Ajuste altura tabuleiro.	Tabuleiro	22-01-2013
8200-PRE-APX-APX03	M.C. -Alteração programa altura tabuleir	Tabuleiro	24-01-2013
8200-PRE-APX-APX03	M.C. -Ajuste altura tabuleiro.	Tabuleiro	24-01-2013
8200-PRE-APX-APX08	M.C. -Ajuste altura tabuleiro	Tabuleiro	25-01-2013
8200-PRE-APX-APX09	M.C. -Ajuste altura tabuleiro	Tabuleiro	25-01-2013
8200-PRE-APX-APX11	M.C. -Ajuste altura tabuleiro	Tabuleiro	25-01-2013
8200-PRE-APX	M.C. -Verificar funcionamento Det.Metais		28-01-2013
8200-PRE-APX-APX11	M.C. -Acompanhar funcionamento máquina.	Sistema de Corte de Cunhas	01-02-2013
8200-PRE-APX-APX07	M.C. -Apoio ao turno "C" nesta avaria.	Extrusora	05-02-2013
8200-PRE-APX-APX10	M.C. -Alteração programa ajuste altura t	Tabuleiro	07-02-2013
8200-PRE-APX-APX11	M.C. -Alteração programa ajuste altura t	Tabuleiro	07-02-2013
8200-PRE-APX-APX01	M.C. -Verificar funcionamento det.metais	Extrusora	14-02-2013
8200-PRE-APX-APX09	M.C. -Substituir barreiras segurança máq	Sistema de Segurança	14-02-2013
8200-PRE-APX-APX03	M.C. -Alteração barreiras segurança máq.	Sistema de Segurança	18-02-2013
8200-PRE-APX-APX01	M.C. -Retificar veio tambor enformação	Tambor de Enformação	28-02-2013
8200-PRE-APX-APX01	M.C. -Analise problemas existentes maq.ª	Alimentação Electrica Geral	06-03-2013
8200-PRE-APX	M.C. -Verificação detetores metais.		12-03-2013
8200-PRE-APX-APX06	M.C. -Colocação chapa fixador cilindro	Tabuleiro	12-03-2013
8200-PRE-APX-APX06	M.C. -Verificar sistema segurança	Sistema de Segurança	12-03-2013
8200-PRE-APX-APX01	M.C. -Virar passadeira transportador	Transportador	14-03-2013
8200-PRE-APX-APX01	M.C. -Substituir 2 cilindros tambor	Tambor de Enformação	14-03-2013
8200-PRE-APX-APX01	M.C. -Sistema corte da cunha direita.	Sistema de Corte de Cunhas	18-03-2013
8200-PRE-APX-APX06	M.C. -Colocar batente corte lamina dir.	Sistema de Corte de Cunhas	18-03-2013
8200-PRE-APX-APX09	M.C. -Alteração programa alimentador/ext	Alimentador de Borracha	18-03-2013
8200-PRE-APX-APX01	M.C. -Fixar guia do tambor enformação.	Carro de Talões	19-03-2013
8200-PRE-APX-APX06	M.C. -Alterar guias cunha após slitter	Slitter	21-03-2013
8200-PRE-APX-APX03	M.C. -Substituir resistência lâmina cort	Sistema de Corte de Cunhas	26-03-2013
8200-PRE-APX	M.C. -Verificar funcionamento Det. Metal		02-04-2013
8200-PRE-APX-APX06	M.C. -Colocação roletes guias slitter.	Slitter	06-04-2013
8200-PRE-APX-APX09	M.C. -Alteração loop alimentador borrach	Alimentador de Borracha	08-04-2013
8200-PRE-APX-APX09	M.C. -Alteração programa alimentador.	Alimentador de Borracha	08-04-2013
8200-PRE-APX-APX09	M.C. -Alteração alimentador da borracha	Alimentador de Borracha	09-04-2013
8200-PRE-APX	M.C. -Verifcar funcionamento Det. Metal		23-04-2013
8200-PRE-APX-APX01	M.C. -Colocar tubo plástico proteção.	Sistema de Corte de Cunhas	23-04-2013
8200-PRE-APX-APX06	MC-Analizar funcionamento da máquina.	Controlo Electrico / Electrónico	29-04-2013
8200-PRE-APX-APX10	MC-Analizar funcionamento da máquina.	Carro de Talões	29-04-2013
8200-PRE-APX-APX01	M.C. -Acompanhar funcionamento máq.ª.	Sistema de Corte de Cunhas	06-05-2013
8200-PRE-APX-APX05	M.C. -Analisar falha contagem talões.		06-05-2013
8200-PRE-APX-APX09	M.C. -Alterar programa motor alimentador	Alimentador de Borracha	07-05-2013
8200-PRE-APX-APX01	M.C. -Verificar funcionamento Det. Metal	Alimentador de Borracha	03-06-2013
8200-PRE-APX	M.C. -Verificar funcionamento Det. Metal		01-07-2013
8200-PRE-APX-APX03	M.C. -Apoio à M. P. no arranque máquina.		04-07-2013
8200-PRE-APX-APX06	M.C. -Apoio à M. P. na avaria nesta máq.	Extrusora	19-07-2013
8200-PRE-APX	M.C. -Verificar funcionamento Det. Metal		24-07-2013
8200-PRE-APX-APX01	M.C. -Ajustar detetor de metais	Alimentador de Borracha	31-07-2013
8200-PRE-APX	M.C. -Verificar detetores metais.		10-09-2013
8200-PRE-APX-APX01	M.C. -Aquecimento ligações contactor.	Controlo Electrico / Electrónico	25-09-2013
8200-PRE-APX-APX04	M.C. -Aquecimento ligações régua bornes.	Controlo Electrico / Electrónico	25-09-2013
8200-PRE-APX-APX11	M.C. -Aquecimento disjuntor SF3 CC	Controlo Electrico / Electrónico	25-09-2013

Appendix II - iCBM_Model (Bizagi Process Modeler)

1. Diagram

Version: 1.0

Author: Francisco A. Ferreira



1.1.1 PROCESS ELEMENTS

1.1.1.1  Element

1.1.1.2  Topic analysis / running investigation /actions results discussion

Description

Based on failure or monitored events, breakdown reports or other important issues (like quality, etc.).

Performers

FBM maintainers, UBM maintainers, DOM maintainers

1.1.1.3 Further investigation needed?

Gates: YES / NO

1.1.1.4 Plan the investigation action

Description

Base on the urgency and the needs of the investigation to plan this action with all the involved departments

Performers

Production Department, Scheduling Department

1.1.1.5 Wait until investigation finished

Description

The topic is suspended until the next meeting where the investigation action results are available

1.1.1.6 Investigation action

Performers

FBM maintainers, UBM maintainers, DOM maintainers, Quality Function, Accounting Function, Procurement Function

1.1.1.7 Actions / action plan discussion

Description

Based on the topic/investigation results analysis, costs, quality and other imputs, to define which is or are the appropriate action(s).

Performers

FBM maintainers, UBM maintainers, DOM maintainers, Quality Function, Accounting Function, Procurement Function, iCBM Coordinator

1.1.1.8 Plan the action(s) / Close actions

Description

Base on the action needs and urgency , to plan the timing and resources for its execution.

Performers

iCBM Coordinator

1.1.1.9 Wait until investigation finished

Description

The topic is suspended until the next meeting where the action(s) results is (are) available

1.1.1.10 Maintenance action (Predictive, Preventive or Repair)

Performers

FBM maintainers, UBM maintainers, DOM maintainers

1.1.1.11 Element

1.1.1.12 Breakdown Report

Description

The report of the maintenance activity in the CMMS.

1.1.1.13 Urgency / Critical analysis (Quality, Safety...)

1.1.1.14 Costs impact (topic and action)

1.1.1.15 Downtime / equipment efficiency (topic and action)

1.1.1.16 Calendar / Machine Scheduled Production

1.1.1.17 Resources allocation

1.1.1.18 Quality reports

Description

Scrap reports, claims, etc.

1.1.1.19 Similar events / topics / experiences

1.1.1.20 Topics analysis in iCBM meetings

2 PERFORMERS

FBM maintainers (Entity)

Failure based maintenance technician.

All the maintainers who belongs to the Corrective Maintenance team.

UBM maintainers (Entity)

Use based maintenance technician.

All the maintainers who belongs to the Preventive Maintenance team.

DOM maintainers (Entity)

Design-out maintenance technicians.

All the maintainers who belongs to the Projects team.

Quality Function (Role)

A representative of the Quality department.

Accounting Function (Role)

A representative of the accounting department.

Procurement Function (Role)

A representative of the Procurement department.

iCBM Coordinator (Entity)

Maintainer Leader (from FBM, UBM or DOM), who has the responsibility to coordinate the actions of the team, as well as to plan the needed resources and machine availabilty.

Production Department (Role)

Scheduling Department (Role)