POLITECNICO DI TORINO

Corso di Laurea Magistrale in Ingegneria Meccanica

Tesi di Laurea Magistrale

Applicazione del pilastro del WCM "Professional Maintenance" in FPT Industrial

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Sommario

Con il presente lavoro si vuole illustrare l'applicazione del pilastro tecnico del Worl Class Manufacturing (WCM) "Professional Maintenance" nello stabilimento Torino Driveline di FPT Industrial. L'elaborato è il frutto di un progetto di tirocinio curriculare finalizzato alla stesura della tesi in azienda.

Il WCM è una metodologia di gestione aziendale che mira all'ottenimento del miglioramento continuo con l'obiettivo di aumentare il valore aggiunto del prodotto eliminando costantemente gli sprechi. Il WCM prende in considerazione dieci ambiti dell'attività di produzione, i quali sono i responsabili della generazione del valore aggiunto del prodotto, che vengono denominati pilastri tecnici e fra i quali troviamo anche la Professional Maintenance.

Il WCM viene introdotto nel mondo FCA da Sergio Marchionne nel 2005 e nel 2007 viene adottato anche nello stabilimento Torino Driveline di FPT Industrial, brand di CNH Industrial che si occupa prevalentemente della produzione nel settore powertrain e nello specifico nello stabilimento Driveline Torino vengono prodotti i sistemi di trasmissione di veicoli IVECO leggere e pesanti. L' adozione della metodologia WCM nello stabilimento ha permesso di raggiungere negli anni obiettivi importanti con un aumento del fatturato, della qualità del prodotto e dell'efficienza del sistema produttivo.

Il presente elaborato si articola in quattro capitoli ed ha come obiettivo quello di dimostrare che l'applicazione corretta del pilastro di manutenzione professionale determina l'eliminazione delle perdite per guasto dovute mancanza di manutenzione con una minimizzazione dei costi di manutenzione.

Il primo capitolo è una panoramica sul WCM e sulle filosofie principali prevalentemente derivanti dal metodo Toyota che rappresentano le fondamenta sulle quali si costruisce il metodo. Vengono descritti in breve tutti i pilastri tecnici andando a contestualizzare infine il WCM nello stabilimento di Torino Driveline.

Nel secondo capitolo invece è illustrato il metodo WCM per quanto riguarda il pilastro di manutenzione professionale. Dopo una descrizione dell'attività di manutenzione viene illustrato il metodo di miglioramento continuo articolato in sette step divisi in tre fasi. La prima fase è quella reattiva e ha come obiettivo l'eliminazione dei guasti mentre la seconda e la terza sono rispettivamente la preventiva e la proattiva con lo scopo di ottenere una riduzione dei costi di manutenzione.

Il terzo capitolo invece rappresenta la parte applicativa del metodo. La teoria illustrata nel secondo capitolo viene applicata su macchine utensili presenti nello stabilimento ottenendo con i primi tre step l'eliminazione delle perdite per guasto. Con lo step 4 invece si va ad allungare la vita dei componenti, con lo step 5 si determina la costruzione di un programma ciclico di manutenzione

mentre lo step 6 determina la costruzione di un sistema di manutenzione predittiva. Lo step 7 mira al management dei costi ma non vi sono ancora esempi applicativi nello stabilimento.

Il quarto capitolo invece è una breve descrizione delle criticità da me riscontrate nella metodologia, con un particolare riguardo alle applicazioni future e allo sviluppo del sistema industria 4.0

Complessivamente l'applicazione della metodologia WCM ha portato all'ottenimento dei risultati voluti e questo elaborato dimostra quanto sia importante utilizzare uno strumento di miglioramento continuo in uno stabilimento di produzione industriale.

Abstract

The aim of this paper is to illustrate the application of the World Class Manufacturing (WCM) technical pillar of "Professional Maintenance" in the Torino Driveline plant of FPT Industrial. The work is the result of a curriculum internship project aimed at writing the thesis in the company.

The WCM is a business management methodology that aims to achieve continuous improvement with the aim of increasing the added value of the product by improving the industrial production activity by eliminating waste. The WCM takes into account ten areas of production activity, which are responsible for generating the added value of the product and which are called the technical pillars of the WCM among which we find the Professional Maintenance.

The WCM was introduced in the FCA (Fiat group) world by Sergio Marchionne in 2005 and in 2007 it was also adopted in the Torino Driveline plant of FPT Industrial , a brand of CNH Industrial that deals mainly with the production in the powertrain sector and specifically in the plant of Driveline Turin are produced the transmission systems of light and heavy IVECO vehicles. The adoption of the WCM methodology in the plant has allowed to achieve important objectives over the years with an increase in turnover, in product quality and in efficiency of the production system.

The present elaboration is articulated in four chapters and has as objective that to demonstrate that the correct application of the pillar of professional maintenance determines the elimination of the losses for failure due to lack of maintenance with a reduction and minimization of maintenance costs.

The first chapter is an overview of the WCM and the main philosophies mainly deriving from the Japanese culture of the Toyota method that represent the foundation on which the method is built. All the technical pillars are briefly described and the WCM is finally contextualized at the Turin Driveline plant.

The second chapter illustrates the WCM method for the professional maintenance pillar. After a description of the maintenance activity, the continuous improvement method is illustrated in seven steps divided into three phases. The first phase is the reactive one and aims at eliminating failures while the second and third are respectively preventive and proactive with the aim of achieving a reduction in maintenance costs.

The third chapter represents the application part of the method. The theory illustrated in the second chapter is applied to machine tools present in the plant obtaining with the first three steps the elimination of faults and relative losses thanks to the construction of a scheduled maintenance program. Step 4 instead extends the life of the components by reducing the load conditions or increasing the strength of the components. Step 5 determines the construction of a cyclic maintenance program while step 6 determines the construction of a predictive maintenance system. Step 7 aims at cost management but there are no application examples because they are not yet executed in the plant.

The fourth chapter is a brief description of the critical issues I encountered in the methodology, with a particular focus on future applications and the development of the Industry 4.0 system.

Overall, the application of the WCM methodology has led to the achievement of the desired results and this elaboration shows how important it is to use a tool of continuous improvement in an industrial production plant.

Acknowledgments

Before proceeding with the treatment, I wanted to offer my thanks to all people who contributed to the realization of this work.

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1 The World Class Manufacturing in FPT Industrial

1.1 The World Class Manufacturing

The World Class Manufacturing (WCM) represents a business management model that aims to create value while ensuring the efficiency of production system.

Richard Schonberger, teacher at the University of Nebraska, used the term World Class Manufacturing the first time in the 80s, to introduce a set of principles of excellence in American companies. In these years, the USA was going through a deep economic crisis that had favoured the rise of Japanese companies. The main cause of this crisis was a bad organization of management system and for this reason Schonberger suggested the introduction of some principles responsible for the Japanese success in the US plants like just in time production (JIT), total quality management (TQM) and overall better organization of human resources.

In the early 2000s, the WCM lost significance replaced by the most influential Japanese models like the Lean Manufacturing of Toyota Production System (TPS), the Six Sigma that is the heir of TQM and the Kaizen Management of Masaaky Imai.

The World Class Manufacturing is back in 2005 thanks to the work of Sergio Marchionne who organized the activities of all plants of the Fiat (FCA) Group according to the rules of WCM. This management model is the main reason for the recent industrial development of FCA group and in this regard, are reported the words of Marchionne who says "the WCM has the objective to make FCA plants flexible and competitive with the best in the world".

The WCM project in FCA group started with experimentation in two pilot plants, Magneti Marelli Corbetta and Venaria Atutomotive Lighting and in 2007, the model was adopted in different plants of the FCA group including the plants of two companies, Fiat Industrial S.p.a and CNH global, which contribute with their corporation at the birth of CNH industrial in 2013.

1.2 The Toyota Production System

The Toyota Production System is a production control system invented by Toyota Motor Corporation. It was introducing between 1948 and 1975 thanks to the work of Sakichi Toyoda, Kiichiro Toyoda and Taiichi Ono.

The TPS is based on two important main topic:

- Jidoka: consist of automation with a human touch because when the problem occurs the equipment stops immediately in order to obtain immediately the quality of the product
- Just in Time: each process produces only what is needed for the next process in a continuous flow.

The TPS can efficiently and quickly produce vehicles of sound quality thanks to a structured production system driven by the principles of Toyota Way

The Toyota Way is divided into 14 principles:

1. Base your management decisions on a long term philosophy: the aim is to generate the value for the customer, society and economy.
2. Create a continuous process flow to brings problems to the surface
3. Use pull system to avoid overproduction: the pull approach consists in producing only what is required
4. Level out the workload (heijunka)
5. Build a culture of stopping to fix problems, to get quality right the first time
6. Standardized tasks are the foundation for continuous improvement and employee empowerment
7. Use visual control so no problems are hidden
8. Use only a reliable, thoroughly tested technologies that serves your people and processes
9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others
10. Develop exceptional people and team who follow your company's philosophy
11. Respect your extended network of partners and suppliers by challenging them and helping them improve
12. Go and see for yourself to thoroughly understand the situation (genchi genbutsu)
13. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly (newmawashi)
14. Become a learning organization through relentless reflection (hansei) and continuous improvement (kaizen)

1.3 Lean manufacturing and WCM

Lean manufacturing is a philosophy of process management that comes from the Toyota Production System. Lean manufacturing aims is to maximize with minimum effort.

The key ideas of lean manufacturing are:

- Identification of the value from the customer's point of view
- Identification of the activities lack of added value (Muda)
- Elimination of Muda with typical instruments of TPS

The Muda are divided into seven categories:

- Defects
- Overproduction
- Transports
- Waits
- Stock
- Movements
- Process

Lean manufacturing and WCM are usually confused and are considered the same strategy but actually, there are some differences

The common aspects of lean manufacturing and WCM are:

- Creation of the value
- Use of typical management instruments of Toyota Production System
- Full involvement of human resources

At the other hand, there are the following differences:

- WCM is not a philosophy but is a complex structured model which aims to continuous improvement
- In WCM the selection of improvement interventions and the priority of implementation are driven by the relationship between cost and benefit (B/C)
- WCM also work to improve the involvement of human resources, the customer care, the safety for the worker and the respect of environments.

In summary, therefore, the lean manufacturing is a philosophy of process management aims to elimination of Muda in according to the rules of TPS while World Class Manufacturing is a company management model, which adopts the majority of instruments of lean manufacturing.

1.4 Kaizen management and WCM

During the 20th century, the preservation of standard was considered a positive achievement for the management activity. In 1986 an important Japanese economist, Imai Masaaki, introduce a new philosophy of continuous improvement, which changed the way of organization of Japanese company by determining their success. This philosophy is called Kaizen from two Japanese words KAI (improvement) and ZEN (better) and is based on the consideration that is always possible change for better. So with this philosophy, the role of the manager became to find the best way to apply these changes together to motivate all human resources to achieve the targets.

The most important tool of Kaizen management is the Deming cycle or PDCA (figure1.1) which consist of a sequence of steps to develop the continuous improvement.

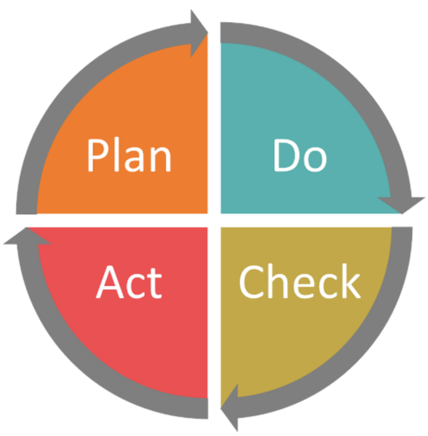


Figure 1.1 – *Deming cycle*

In the Deming cycle, there are four steps:

- Plan: consist to identify the problem, to isolate the real cause and to define corrective actions
- Do: consist of the execution of the program that is defined in plan
- Check: consist to verify the results and compare them with target
- Act: consist of the standardizations and preparations of the next stage of plan

The improvement achieved with PDCA become the standard for the next cycle, for this reason is possible to obtain a little improvement every cycle.

Kaizen management is based on small steps and this practice does not require large investments, while still providing result stable over time and large involvement of human resources. It is a philosophy or an instrument of lean manufacturing while WCM is a complete methodology. Kaizen and WCM complement each other in the dynamics of improvement of pillar activities.

1.5 The OSAT approach

A system is defined interdependent if is composed from processes that determine results depending on the other processes. Interdependent system is like a chain featured by different links that are the processes.

To achieve the best result must be strengthened the weakest link, in fact, a local improvement of stronger links does not determine a global reinforcement of chain but it is only a waste of resources or a Muda.

In WCM, the target is to maximize not only a singular process but all processes that composed the company activity. The management strategy must aim to reach the main objective, which is possible only thanks to the good work of each employer and also there must be collaboration and not competition between all parts of the company.

The methodology to achieve this target is the OSAT approach (Objective, Strategy, Action, Target), which is widely shared by the WCM system.

The OSAT approach includes four phases:

- Objective: preliminary analysis and definition of target
- Strategy: planning of secondary objective to reach the main target
- Action: tool of problem-solving and problem setting
- Target: verification of achieved targets in relationship with planned targets

This approach must require a stratification of objectives in different levels of importance in order to reach the main target and also require a continuous monitoring of results. For this reason is important to define a group of indicators that are used to analyse the performance in relationship with the target. These indicators are called key performance indicators or key performance index (KPI).

1.6 The WCM model

The World Class Manufacturing model is based on two main aspects:

1. The development of the value through the minimization of Muda
2. The evaluation of the benefit-cost ratio

The model consists of a program structured in 10 technical pillars, one for each business aspect possible to improve, which arrange their activities through a seven-steps program (figure 1.2) aims to reach the excellence in every field of the company. These steps determine the continuous improvement and allow the company to move from a reactive state to preventive and after to proactive state, where:

- Reactive: countermeasures realized after one event
- Preventive: countermeasures realized on the base of past experience in order to avoid the event repetition
- Proactive: countermeasures aimed to avoid that an event happens on the base of a theoretical risk analysis

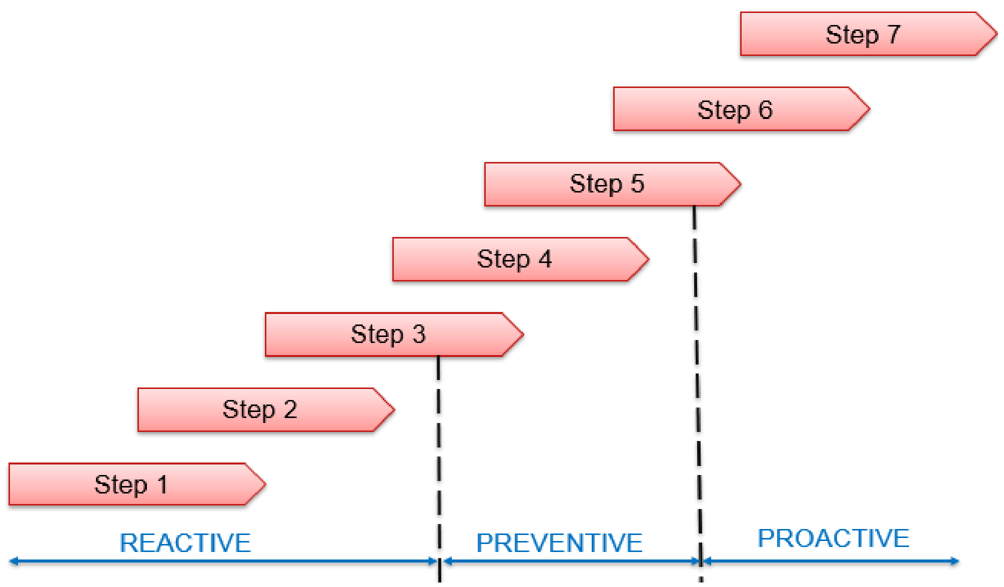


Figure 1.2 – *The seven steps of WCM*

The structure of WCM also provides for the use of 10 managerial pillars, which are the tools of WCM and they are helpful during the upgrading of seven steps in each pillar. These tools come from the Toyota Production System and are featured by simplifying of topics and by dynamic of application. These managerial pillars are:

1. Management commitment
2. Clarity of objectives
3. Route map to WCM
4. Allocation highly qualified people

5. Commitment of organization
6. Competence of organization toward improvement
7. Time and budget
8. Level of detail
9. Level of expansion
10. Motivation of operators

1.7 Technical Pillars

The objective of manufacturing companies is satisfy customer needs through:

- Quality of product
- Excellent service
- Sustainable cost

For this reason, originally, the WCM develop its method around four aspects:

- Total Industries Engineering: engineering techniques applied to all frames of production system with target zero waste
- Just In Time: to produce when is necessary with target zero inventory
- Total Productive Maintenance: maximization of business efficiency with a complete program of maintenance with target zero breakdowns
- Total Quality Control: a global vision to manage quality control with target zero defects

Later the World Class Manufacturing has developed a complex model structured in ten technical Pillars (figure 1.3):

- CD- Cost Deployment
- FI- Focused Improvement
- EEM- Early Equipment Management – EPM- Early Product Management
- AM- Autonomous Maintenance- WO- Work Place Organization
- PM- Professional Maintenance
- SH- Safety and Health
- EN- Energy- ENV- Environment
- LO- Logistic and Customer Service
- PD- People Development
- QC- Quality Control

The pillar activity is characterized by two different approaches:

- Systemic approach: starts from the identification of a problem which is addressed and resolved with a seven steps program. This approach is typical of long term vision
- Focused approach: starts from the identification of loss which is shows from the activity of Cost Deployment or from QA or S matrix. It's typical of short term vision

In the following table are summarised the type of approach for each pillar:

Pillar	Approach
CD- Cost Deployment	Focused
FI- Focused Improvement	Focused
EEM- Early Equipment Management – EPM- Early Product Management	Systemic
AM- Autonomous Maintenance- WO- Work Place Organization	Systemic
PM- Professional Maintenance	Systemic
SH- Safety and Health	Systemic
EN- Energy- ENV- Environment	Systemic
LO- Logistic and Customer Service	Focused
PD- People Development	Focused
QC- Quality Control	Focused

Table 1.1 – *Technical Pillars approach*

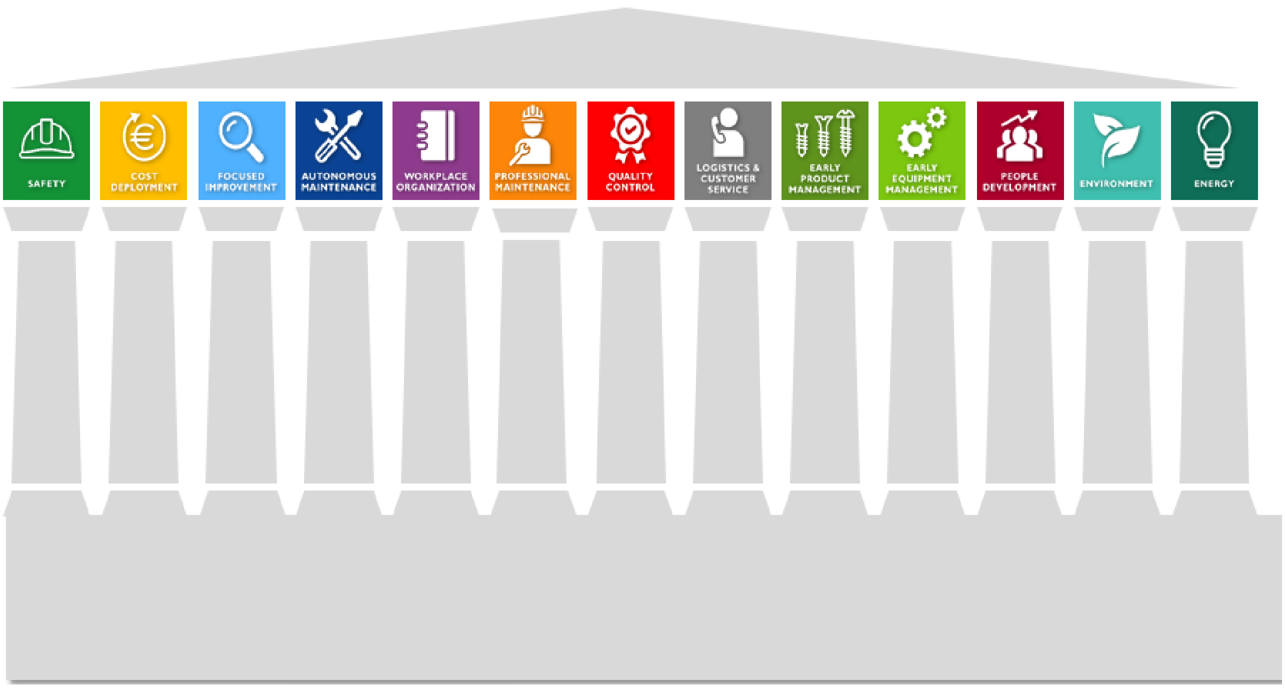


Figure 1.3 – *Technical Pillars*

1.7.1 Cost deployment

Cost deployment aim is to obtain a continuous improvement with a direct explanation of the costs about the interventions carried out to show the positive results reach thanks to the application of WCM method and to identify the loss causes and wastes.

The activity of CD move from the localization to the evaluation of losses and with the application of different methodologies try to delete these losses by quantifying the expected benefits.

The seven steps of the CD are:

1. Identify total factory costs, establish a target for cost reduction and separate total costs by different processes
2. Identify wastes and losses qualitatively, identify wastes and losses based on pasted operating data or based on the measurements of wastes and losses quantitatively
3. Separate casual losses and resultant losses
4. Translate identified wastes and losses
5. Identify methods to recover wastes and losses
6. Estimate costs for improvement and the amount of possible cost reduction
7. Establish improvement plan and its implementation, follow up and repeat the stage 4

1.7.2 Focus improvement

Focused improvement is the technical pillar that deals with attacking the main losses, identified by Cost Deployment, which have a significant impact on the budget. The FI activities are the definition of targets and resources to be used for each project, training and monitoring of teamwork, realization thanks to specialist support of the projects and certifications of the results. The aim is to get costs reduction through improvement of plant efficiency, a reduction of set-up time and wastes and a professional growth with a complete acquisition of the WCM method.

The seven steps of the FI are:

1. Establish the main topic
2. Losses stratification
3. Decide one topic
4. Build the team
5. Project with a correct method
6. Costs and benefits analysis
7. Follow up and horizontal expansion

1.7.3 Early equipment management and early product management

The WCM awards considerable importance to the result of improvement projects, in fact, there is a technical pillar that covers this aspect. This pillar is featured by the Early Equipment Management EEM and by the Early Product Management EPM, where:

- EEM works in term of start up a new equipment in established time with costs optimization
- EPM is responsible for the process engineering with a study of strategies in order to find the best way to reach the target

The seven steps of EEM are:

1. Planning: identification of targets and strategy
2. Basic design: analysis of necessary facilities and their cost
3. Detailed design: deepening of strategy

4. Manufacturing: the production phase
5. Installation: installation of the equipment in the shop floor
6. Trial production: operation of the line testing
7. Initial flow: launch of the product

The benefits of the EEM applying are:

- Simplifications of maintenance activities
- The equipment standards ensure that the purchase of new equipment avoids the reappearance of problems already faced and resolved
- Reduction of delivery time
- Operating costs reduction

The seven steps of EPM, instead, are:

1. General planning
2. Targets definition
3. Concept definition
4. Product and process design and testing
5. Equipping for production
6. Pre-series
7. Production monitoring

1.7.4 Autonomous maintenance

The autonomous maintenance of the machine is an important aspect of the manufacturing process because the equipments are usually under degraded conditions, the equipment efficiency no satisfy the targets and is possible to improvement operators motivation.

The activities of the AM are the building of a team, the starting cleaning, the elimination of dirty sources, the application of cycles of cleaning, inspection, lubrication and clamping. Moreover, for the AM pillar is important to train the workers in order to improve product quality.

The seven steps of AM are:

1. Initial cleaning and inspection
2. Countermeasures against sources of contamination
3. Initial standards
4. General inspection
5. Autonomous inspection
6. Improvement of standards
7. Full-scale application of the autonomous maintenance system

The benefits expected with a correct application of the AM principles are:

- Improvement of overall equipment efficiency (OEE) and product quality
- Increase of equipment's life
- Improvement of motivation and pro-activity

1.7.5 Workplace organization

The workplace organization represent with the AM the pillar of autonomous activities. The WO is important because workplace, materials and equipment are usually degraded and dirty.

The activity of the WO pillar consists of creation and training of the team, cleaning and reorganization of workplace, definition and application of maintaining cycles, individuation and elimination of no added value activity and improvement of product quality.

The seven steps are:

1. Initial cleaning
2. Tidying-up process
3. Tentative standards
4. Product characteristics education
5. JIT parts supply
6. Standardization
7. Standard work sequence

The benefits of WO application are:

- Elimination of manpower or materials losses
- Increase of product quality
- Improvement of productivity with appropriate cost of process
- Ergonomic and safety work conditions

1.7.6 Professional maintenance

The professional maintenance is the pillar that organize the activity of the maintenance team. The maintenance team occurs in case of breakdown and in all maintenance operations that are not planned for the conductor.

The PM is important because there is a large number of breakdowns, there is not a structured and systematic activity of preventive maintenance and there is not a deep collaboration between conductors and maintenance team.

The activities of PM are the monitoring and analysing of breakdowns, the improvement of maintainer skills, the definition of a plan of scheduling maintenance and also try to collaborate with the AM teams.

The seven steps of PM are:

1. Elimination and prevention of accelerated deterioration
2. Breakdown analysis
3. Maintenance standards
4. Countermeasures against weak points of the machine and lengthened equipment life
5. Build a periodic maintenance system
6. Creation of a predictive maintenance system (management trends)
7. Maintenance cost management: the establishment of a planned maintenance system

The benefits expected are:

- Breakdowns reduction
- Increase of OEE
- Increase of the percentage of planned maintenance
- Motivation and professional growth of maintenance team
- Better collaboration between conductors and maintainers

1.7.7 Safety

This pillar is important to meet the needs of employers ensuring a continuous improvement of safety on the workplace.

This condition is possible with the organization of periodic audit about the safety of equipment and the identification and the evaluation of dangers and risks. Moreover, it is important to analyse the happenings incidents in order to improve technical aspects of machines conditions and of the workplace. For this reason, the SA provides for many activities of control and training.

The seven steps of SA are:

1. Analysis of accidents and their causes
2. Countermeasures and horizontal expansion
3. Setting tentative standards for safety
4. General inspection for safety
5. Autonomous inspections
6. Autonomous safety standards
7. Full implemented of safety management

The results of the correct application of the SA are:

- The improvement of the working environment
- The elimination of the condition for accidents and injuries

1.7.8 Energy and environment

This pillar is used to satisfy the needs of employers and civil society ensuring at the same a correct respect of the environment and energy consumption.

The main activities of this pillar are the organization of internal periodic audits about the impact of the plant on the environment, identification and prevention of the risks, the application of ISO 14000, a technical improvement on the equipment and operation of training and control.

The steps of this pillar are:

1. Understand local environmental laws and regulation
2. Eliminate the environmental pollution causes
3. First attempt standard horizontal expansion of step 2 (environmental internal audit)

4. Control of chemical risk, natural resources and energy saving
5. Set up a system of environmental management with reporting system and economical budget
6. Set up a system to reduce the environmental impact and suppress the risks. Use ecological sources for the purchased materials
7. Complete use of the environmental management system

The benefits determinate by this pillar are:

- Reduction of the energy consumption
- Reduction of the generation of noise and pollutants
- Improvement of the working environment
- Elimination of the causes for possible environmental accidents

1.7.9 Logistic and customer service

The correct application of this pillar is essential because the stocks of material are high with an important cost and with an increase of the obsolescence and the risk of deterioration. In addition, should organize the supply chain to accommodate the needs of the customer.

The main activities are the application of the flow analysis (value stream map) for the individuation of losses and opportunities, the improvement of programming system, layout and packaging. The logistic method work around the different methodologies of materials management like the just in time (JIT), Kanban and FIFO.

The steps are:

1. Reengineer assembly to satisfy the customer
2. Recognize internal logistics
3. Recognize external logistics
4. Level out of production
5. Refine internal and external logistics
6. Integrate the purchasing department
7. Adopt defined time sequence programming

The expected benefits are:

- The stock reduction
- The reduction of deterioration and the materials obsolescence
- The improvement of logistical skills

1.7.10 People development

Notoriously the growth of the Company coincides with the growth of the human resources. The people development pillar becomes a fundamental pillar because the competence of the employers and their ways of work are usually inappropriate, the system of evaluation and competence development is lacking. The PD aims to support the skills in a targeted way to develop methodologies and projects of continuous improvement.

The activities of the PD are the mapping of necessary and owned skills with the radar chart, the gap analysis, the definition of training plan with the organization of the training labs.

1. Definition of principles and priority of training system
2. Definition of starting training system to develop the competences
3. Development of the system for the improvement of competences
4. Introduction of a training system
5. Development of the system for advanced competences
6. Development of distinctive skills
7. Continuous assessment to obtain continuous improvement of human resources skills

The benefits of a correct application of PD rules are:

- The application of quality control to reach an improvement of product quality
- Better competences of the autonomous and professional maintenance team
- Zero human errors
- The reduction of accidents risk
- The increase of motivation

1.7.11 Quality control

The quality control pillar is used because the customer satisfaction is inappropriate, a component with defects arrive to the customer and because wastes and reprocessing have a high cost.

The activity of the QC consist of defects, reprocessing and wastes tracking to analyse the causes of these problems (QA matrix), the definition of operating conditions that ensure the desired quality and the process capability (QM matrix), the compiling of X matrix and definition of the Q points, the definition of prevention and maintenance cycles and the definition of Standard Operating Procedure (SOP).

The seven steps are:

1. Select topic
2. Understand situation: collect data and define targets
3. Action plan
4. Causes analysis
5. Consider and implement the countermeasures
6. Check results
7. Standardize and establish control

The benefits are:

- The increase of customer satisfaction
- The reduction of wastes, defects and reprocessing that is the cos of non-quality
- The spread of problem solving competences
- The improvement of the quality of the products

1.8 The audit system

The activities of WCM are monitoring with a system of periodic audits, which is an important element in assessing, guiding and supporting in relationship with the application of the method. A WCM audit is directed by a group of external auditors, typically from WCM central team, and aims to the evaluation of the most important KPI for each pillar. At the end of the audit, the plant receives a technical evaluation that shows the strength and the criticalities with a program of improvement which will be verified in the next audit. The audit system is also featured by an evaluation system which determines a score of the plant and is possible to create a ranking with all plants.

The evaluation system is based on:

- Technical pillar: from 0 to 5 points for each pillar, based on 7 steps
- Managerial pillar: from 0 to 5 points for each pillar, based on 5 steps

The score of the pillar is an evaluation composed by the level of detail and the level of expansion (figure 1.4)

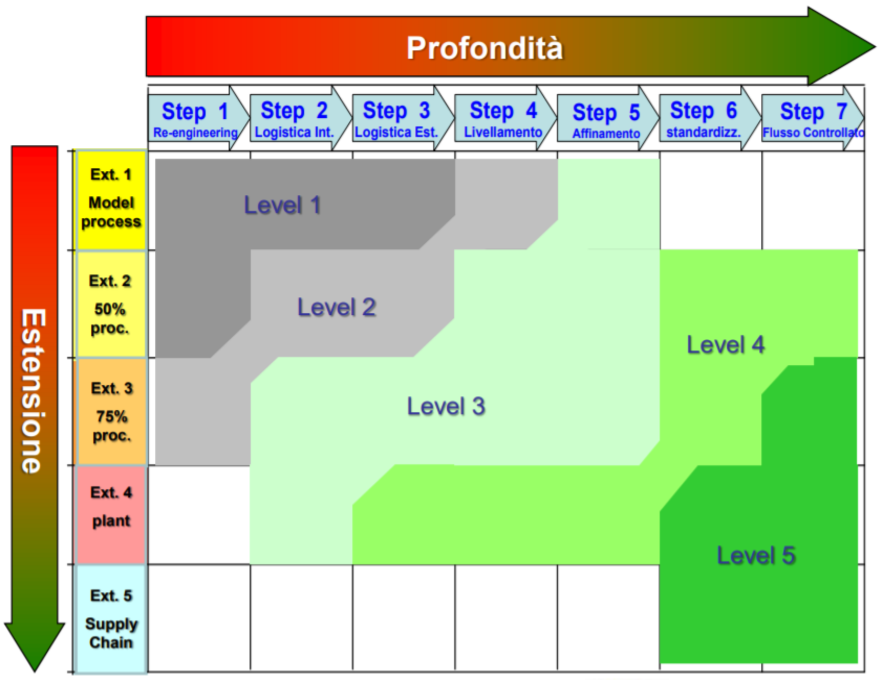


Figure 1.4 – *Level of Detail and expansion*

The score of pillar identifies the following situations:

- [0]: not started, no reach target, uncorrected application
- [1]:reactive approach
- [2]:preventive approach: model areas
- [3]:preventive approach: expansion in plant
- [4]:proactive approach: model areas
- [5]:proactive approach: expansion in plant

With this type of scoring is possible to obtain from 0 to 100 points and there are some award levels:

- Bronze: 50 points
- Silver: 60 points
- Gold : 70 points
- WCM award: 85 points

1.9 FPT Industrial S.p.a

FPT Industrial S.p.a. is a brand of CNH Industrial, leader in development, manufacturing sale and assistance of innovative solutions of powertrain for vehicular application on-road and off-road, marine engines and power generation.

The company was born in 2011, after a partial split of Fiat Group that marks the birth of the new group of Fiat Industrial. With ten manufacturing plant and six R&D centres is located worldwide with about 8000 employees.

FPT Industrial works linked to the other brand of CNH industrial in different fields like the agriculture (Case IH, New Holland Agriculture and Steyr), the construction (Case Construction Equipment, New Holland Construction), and the Industrial vehicles (Iveco, Iveco Bus, Heuliez Bus, Iveco Airbus, Magirus, Iveco Defence Vehicles).

The production of FPT industrial is about:

- Engines (on-road, agriculture, construction, marine and powertrain generation)
- Drivelines (axles and transmission)
- Technologies (Hi-ESCR and alternative fuel)

FPT Industrial adopts the World Class Manufacturing program that encompasses all processes (emission management, maintenance, logistics, quality…) with the objective of constantly improving safety, working conditions, performance, efficiency and flexibility. The ultimate aim of WCM is reduce to zero inefficiencies, defects, waste and accidents, and this objective is pursued through people involvement and motivation.

1.10 Driveline Plant

The Driveline Plant is located in Turin and represent together with Engine Plant the Turin site of FPT industrial.

The location of the plant is showed in the figure 1.5 where we can find the Driveline areas with axles and transmission, the Engine plant and the testing.

The size of Driveline Plant is about 241.000 m^2 with 1015 employees. The plant adopts the Worl Class Manufacturing method in 2007 and now is running to gain the Gold Award as is shown in the figure 1.6.

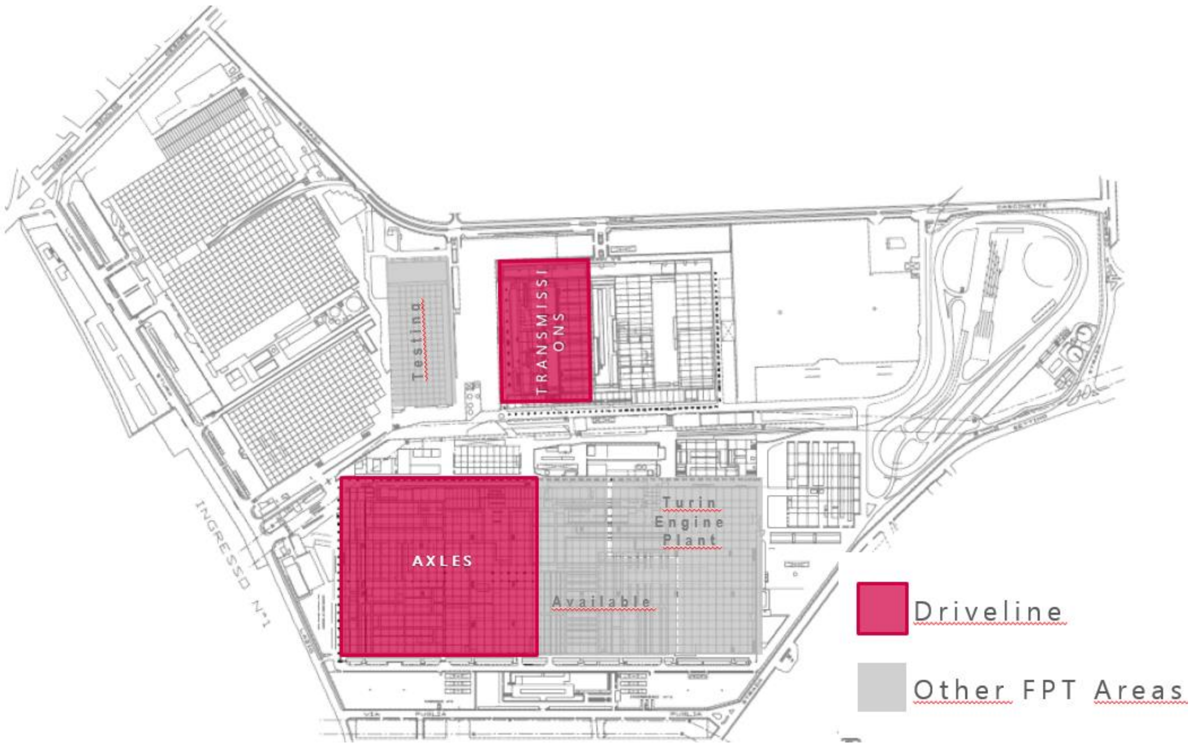


Figure 1.5*-Turin site*

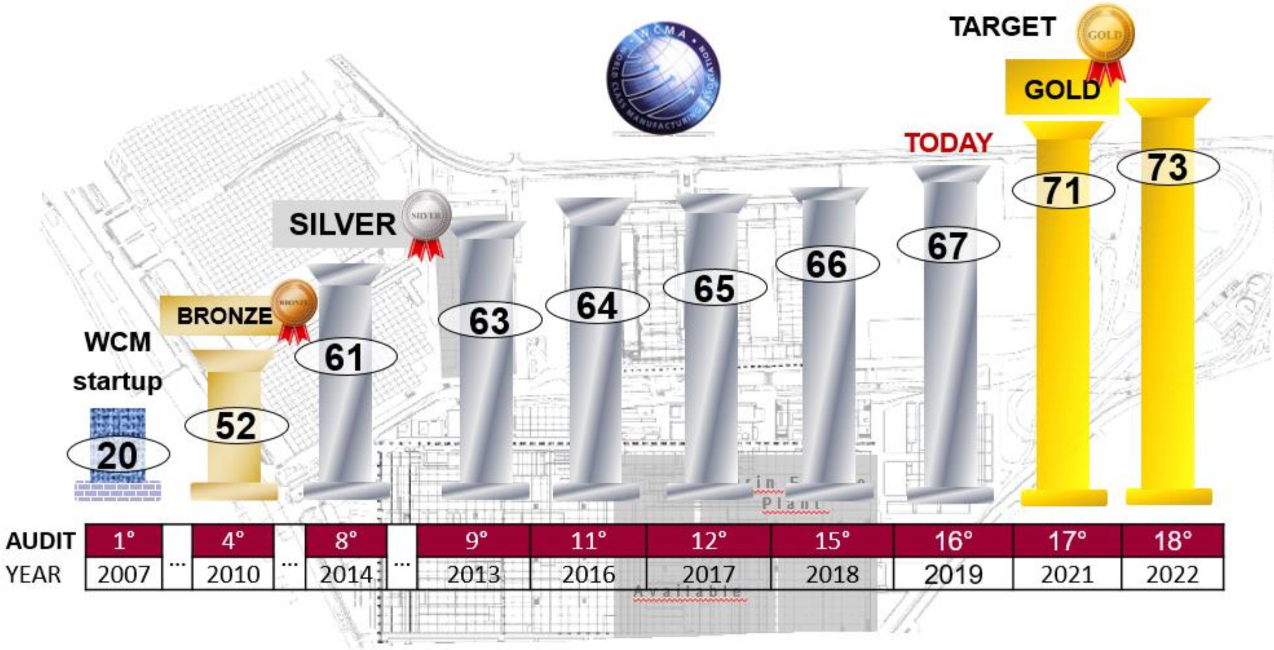


***Figure 1.6**-WCM Ranking*

The current axles and transmission portfolio of Driveline Plant is the following:

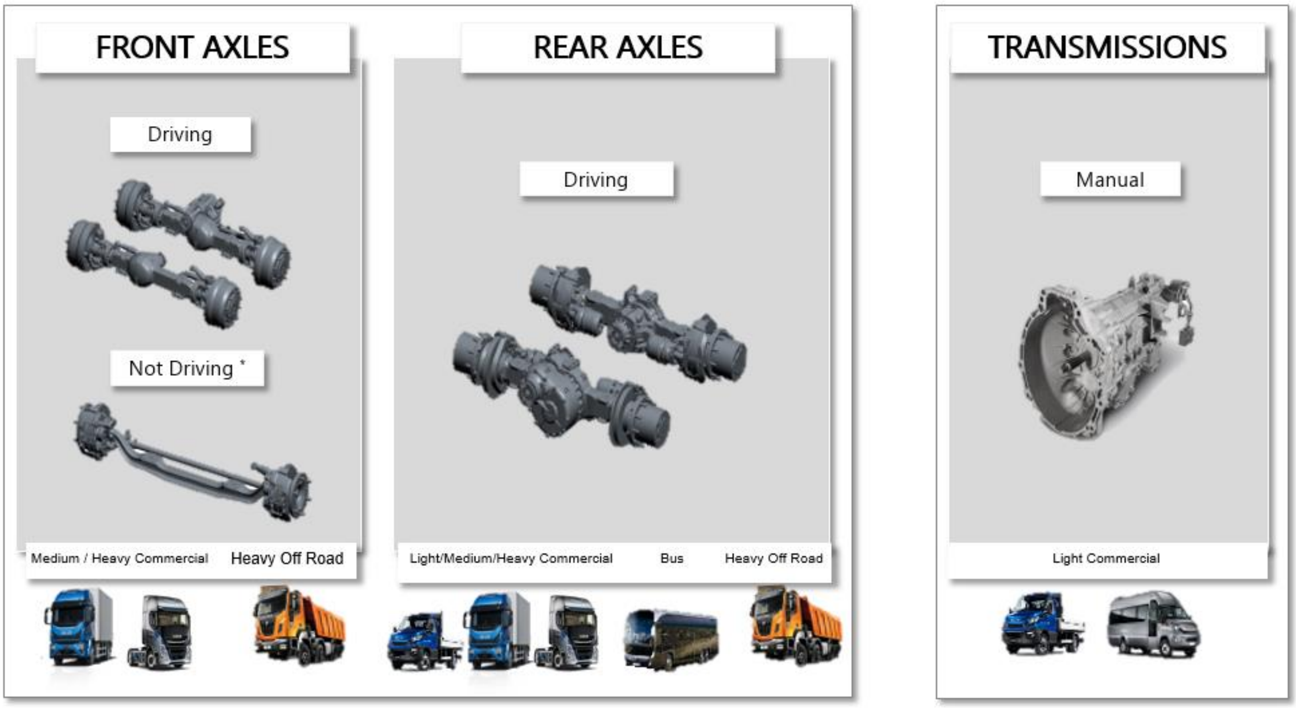


***Figure 1.**7-Driveline Portfolio*

The plant is structured by different Operative Units (UO):

- Transmission
- Axles Machining
- Axles Assembly
- Heat Treatment – Bevel Gears- Engine Gears

Each Operative Unit is divided in different UTE.

The activity of the Operative Units is linked with the activity of the other departments of the plant:

- PTS- Plant Technical Support
- Human Resources
- Quality
- Finance
- Logistics
- Environment and Safety
- Work Analysis
- WPS
- Launch

1.10.1 The axles area

The axles areas (figure 1.8) includes different UO like Axles Machining, Axles Assembly, Bevel Gears and Engine Gears.

The Axles Machining is divided in four UTE:

- UTE 7.01
- UTE 7.02
- UTE 7.03
- UTE 7.05

The Axles Assembly is divided in three UTE:

- UTE 7.08
- UTE 7.09
- UTE 7.10

The Bevel Gears consist of UTE 7.07 and the Engine Gears consist of UTE 1.10

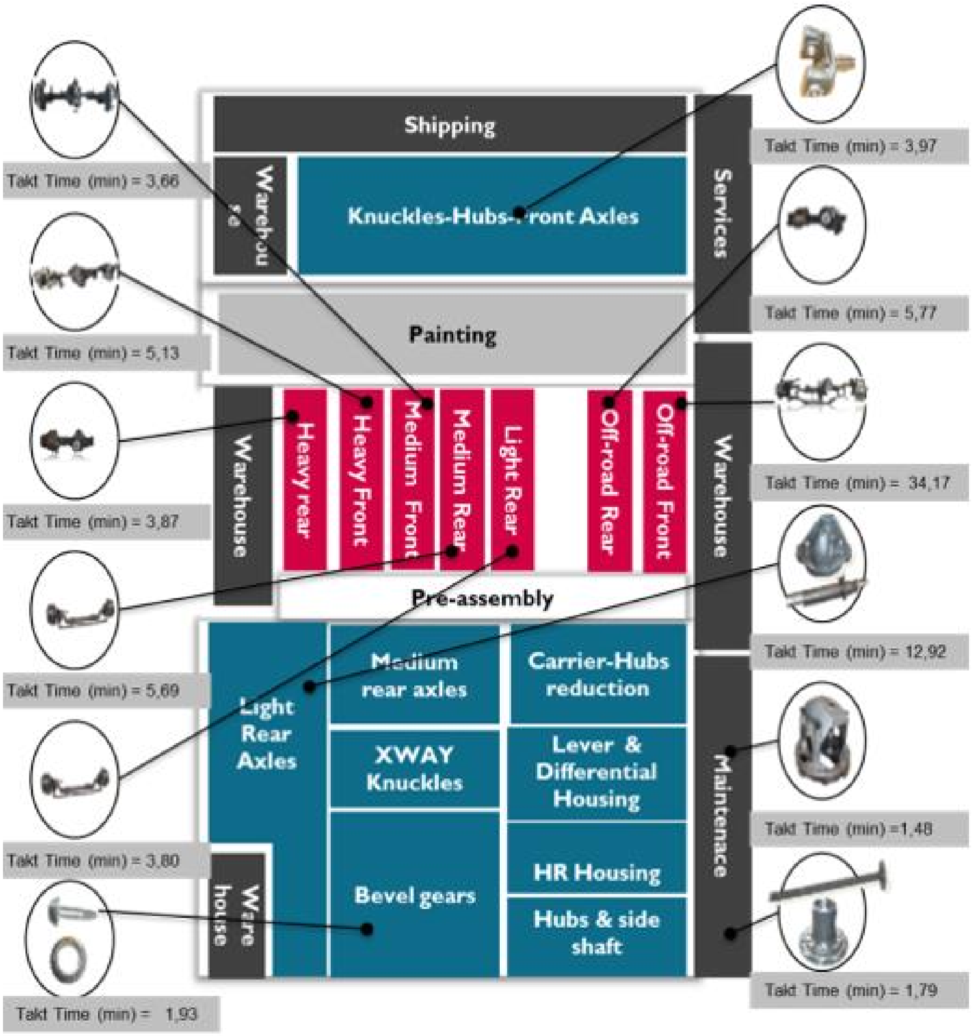


***Figure 1.8**- The axles area*

In the machining area there are 137 axles machines, 44 engine gears machines and 38 bevel gears machines while the assembly area is composed by 7 lines, 104 workstations and 12 machines.

In the following figure (figure 1.9) is shown the material flow:

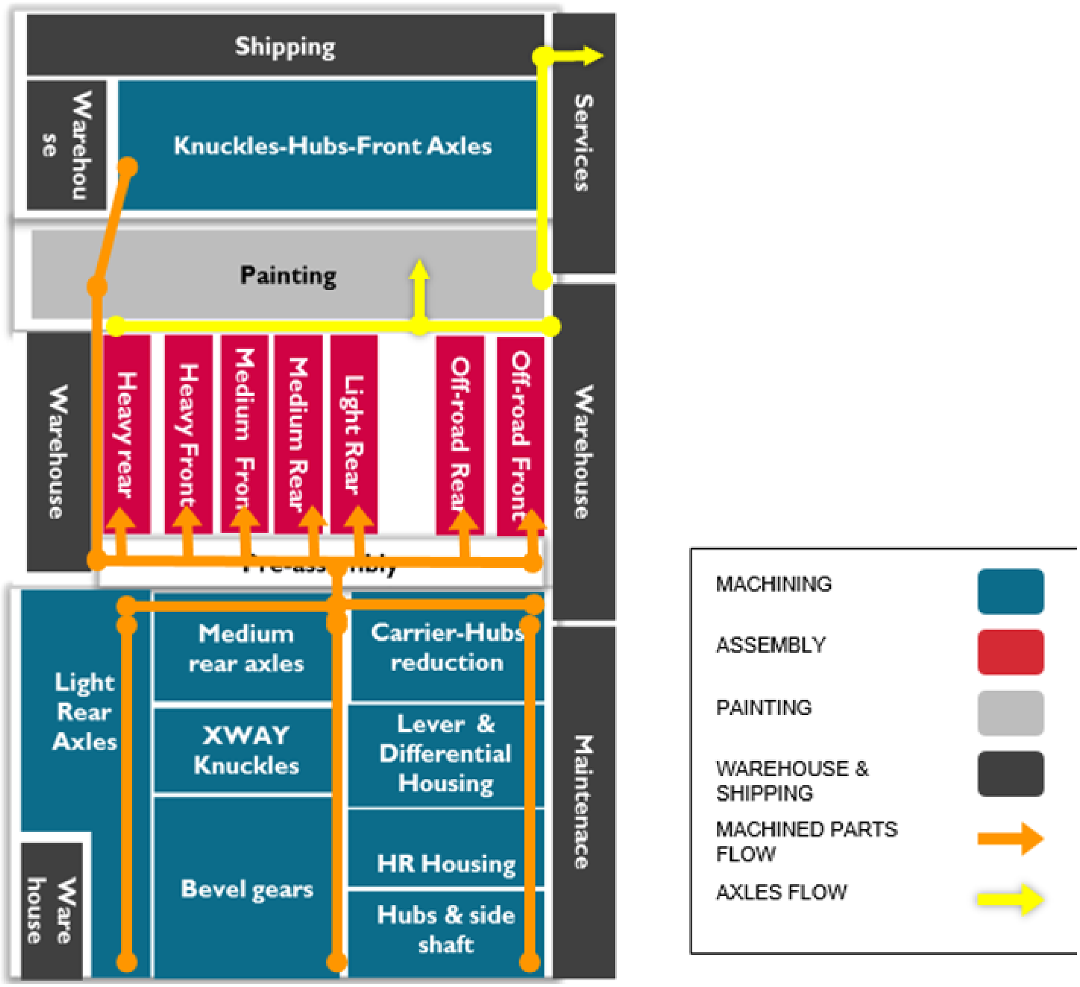


Figure 1.9- *Material flow axles*

1.10.2 The transmissions area

The transmission area (figure 1.10) is divided in transmission machining and assembly and in heat treatment.

The transmission machining is divided in three UTE:

- UTE 1.01
- UTE 1.03
- UTE 1.04

The transmission assembly is divided in three UTE:

- UTE 1.06
- UTE 1.07
- UTE 1.08

The heat treatment consist of UTE 1.05

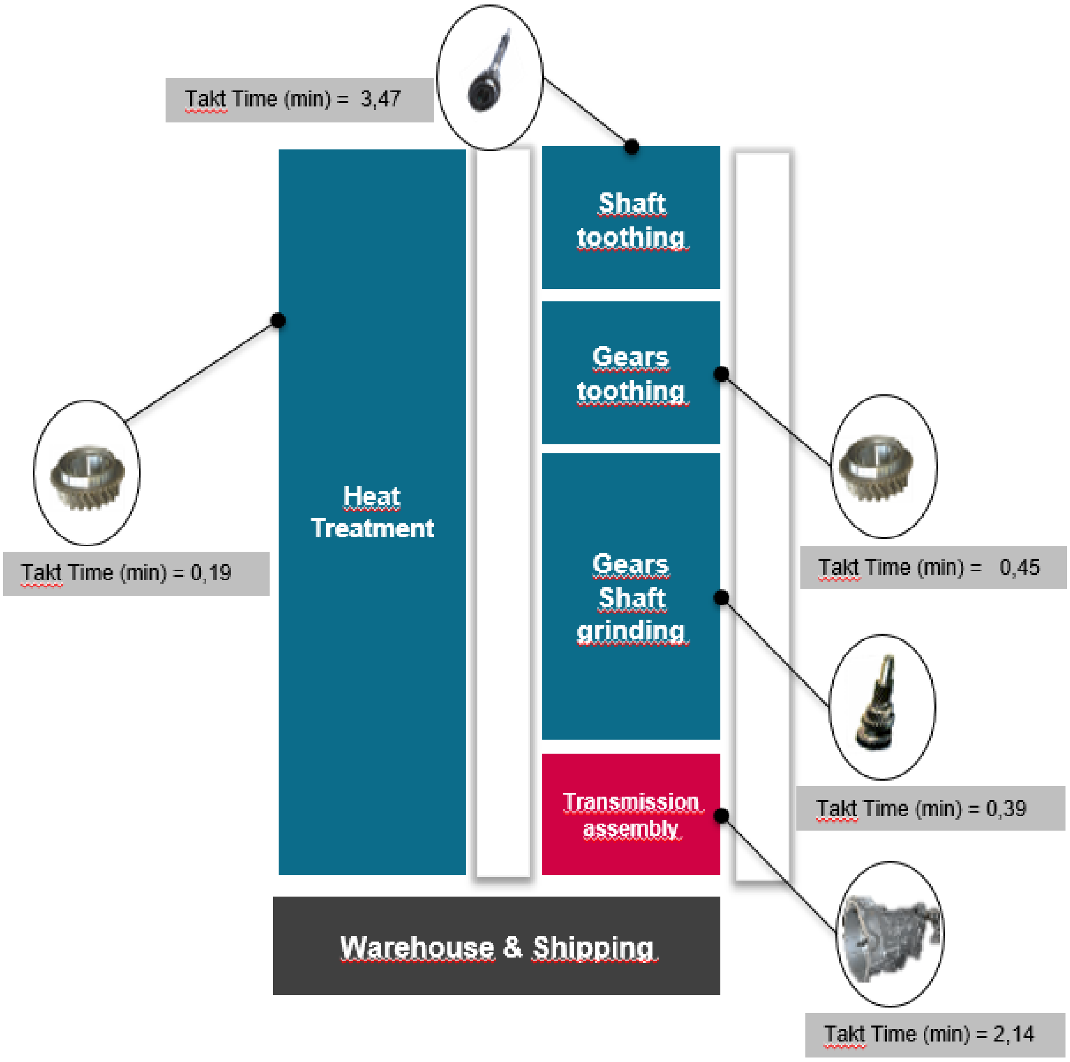


Figure 1.10- *Transmissions area*

The machining area is composed by 55 machines, the assembly consist of 1 Lines, 33 workstations and 11 machines. The Heat Treatment area is featured by 1 Annealing furnaces, 5 cementation furnaces, 1 Laser welding, 2 Shot peening and 2 Shot blasting.

The material flow of transmission area is shown in the following figure:

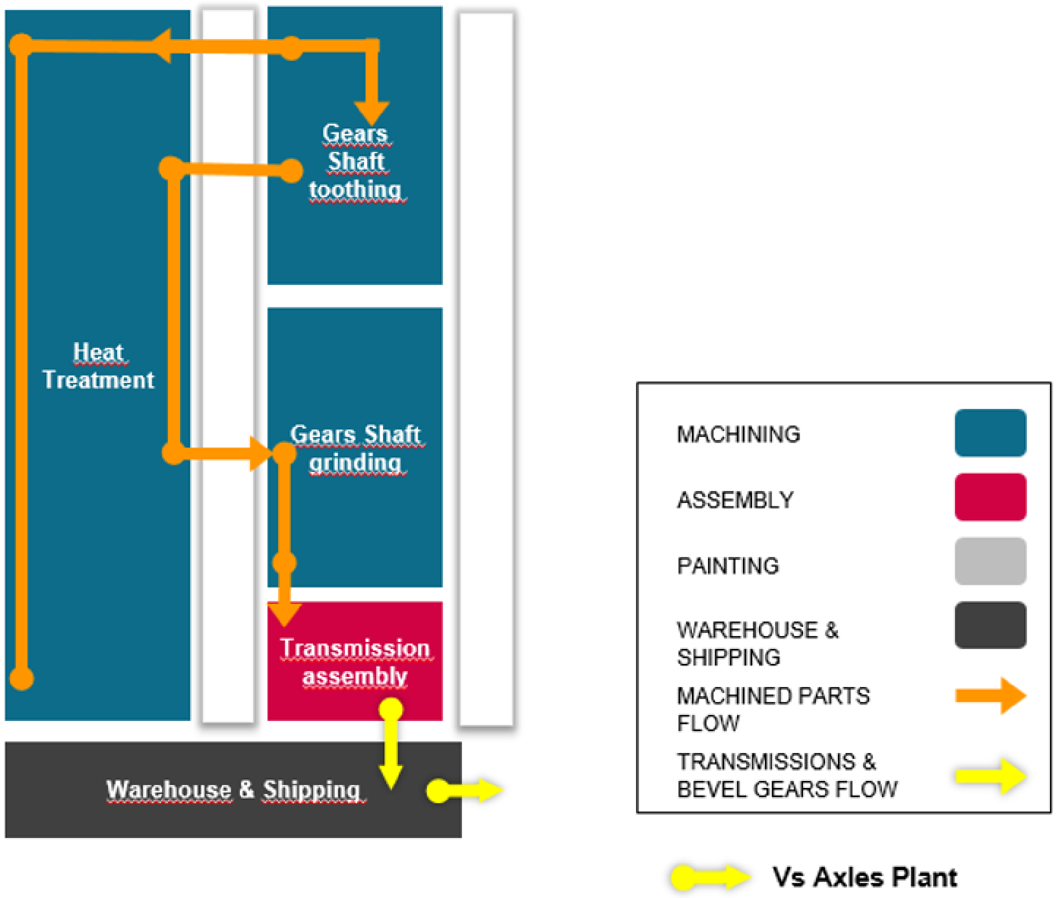


Figure 1.11- *Material flow transmission*

1.11 Plant Technical Support

The Plant Technical Support (PTS), the technical institution of the plant, carries out activities of maintenance, of the qualitative characteristics, of reliability, safety and energy consumption of plant assets. The PTS is the reference body for the introduction of technological innovations and process improvement activities within the plant and towards the central technical entities.

The activities of PTS are:

- Re-engineering of process
- Process Quality
- Internal production efficiency initiatives
- Increases in domestic production capacity
- Changes in production allocations
- All those internal plant activities not covered by the Plant's profit and loss account

The role of PTS is shown in the following figure:

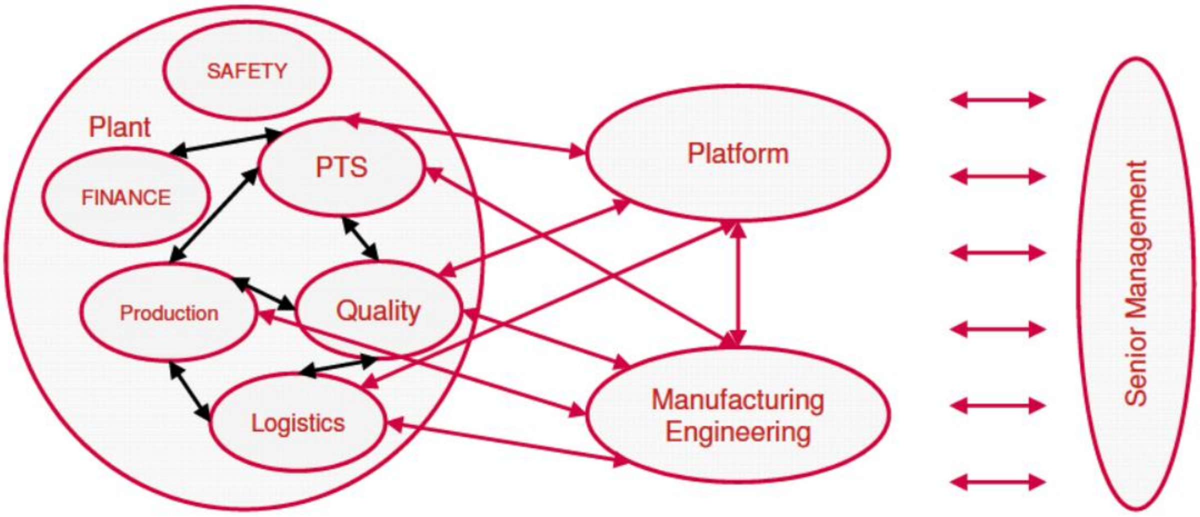


Figure 1.12- *The PTS role*

The Plant Technical Support plays a major role in the design of the feasibility study and technical and economic evaluation of preliminary proposals for improvement. The PTS has a transversal position of coordination of activities, during the data collection phase aimed at the processing of investment budget, based on the following factors:

- Technical specifications of the proposed solution
- Objectives and performance
- Timing of implementation

The PTS is organizated in the following way:

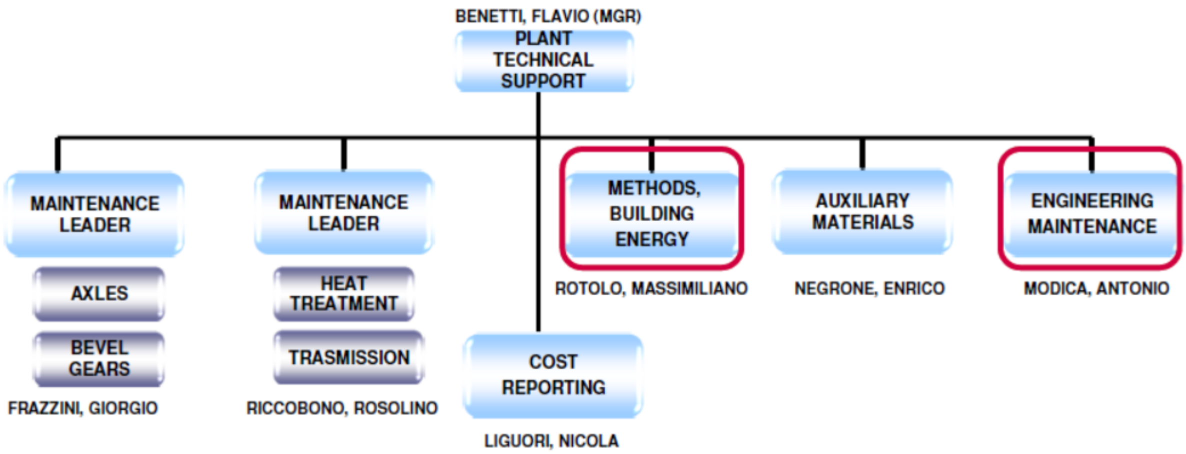


Figure 1.13- *The PTS organization*

1.11.1 Maintenance engineering

My role in the internship project was the support of maintenance engineering activities and the support in the application of the rules of the World Class Manufacturing in relationship with the Professional Maintenance Pillar.

Maintenance Engineering is the unit responsible for the design and control of the maintenance system. The activity of maintenance engineering consist of:

1. Performs machine classification (Impacts and losses caused by machine downtime)
    - Reactive and Preventive Classification
    - Definition of intervention priorities according to the production scenario
2. Defines the tertiary structure of maintenance activities
    - Technical assistance contracts
    - Interventions carried out by external suppliers
3. Defines maintenance policies
4. Management and standardization of spare parts
5. Head of Supporting Information Systems
6. Defines detects and analyses maintenance performance and cost indicators

2 Professional Maintenance Pillar in CNH

The plant is a complex place where there are different problems related to people and machines. However, the major problem of plant is to use equipment in an optimal way with well organized maintenance. Equipment is designed to be reliable; the machine is composed by different types of components but only when a component fails the machine breaks down. The aim of maintenance is not only to eliminate breakdowns but is how to do it economically.

2.1 Types of maintenance

There are different types of maintenance:

- Breakdown maintenance (BDM)
- Autonomous Maintenance (AM)
- Time Based Maintenance (TBM) or periodical
- Predictive Maintenance IR (inspections and repairs)
- Hit Based Maintenance (HBM) or cyclical
- Conditions Based Maintenance (CBM) or predictive
- Corrective Maintenance (CM)

2.1.1 Breakdown Maintenance

The BDM operates on machine only when the breakdowns occurs (figure 2.1). This kind of maintenance can be chosen when:

- The Breakdown of the component doesn't stop the machine
- The cost of preventive maintenance is more than the losses caused by the stop of machine
- There isn't impact in terms of safety

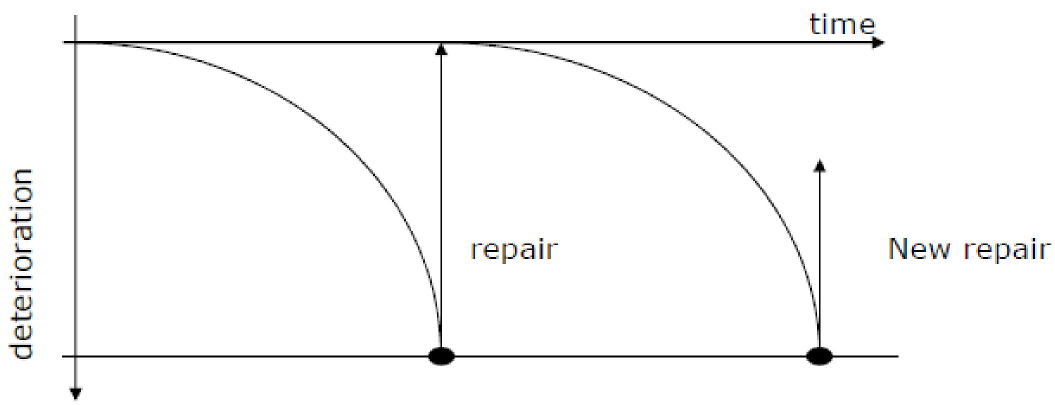


***Figure 2.1**-Breakdown Maintenance*

The advantages of BDM are:

1. Low costs
2. No needs of plans but only spare parts availability
3. Requires of limited maintenance competencies
4. Components utilized at maximum sustainable stress

The disadvantages of BDM are:

1. No early warnings of failures
2. Uncontrolled Production losses
3. Requires a large number of maintenance people available

2.1.2 Autonomous Maintenance

The AM is performed by the workers directly on production lines. Operator have to maintain normal working conditions of machines and devices as well as to restore the initial conditions. The aims of AM are:

1. To reduce the number of breakdowns due to lack of basic conditions
2. Minor failures
3. Minor errors connected with work of machines and devices

2.1.3 Time Based Maintenance

The TBM maintenance operates on machine periodically with a frequency based on time (figure 2.2) in order to prevent breakdowns and stoppages. TBM is applicable if the overall cost of maintenance is less than the cost of breakdown.

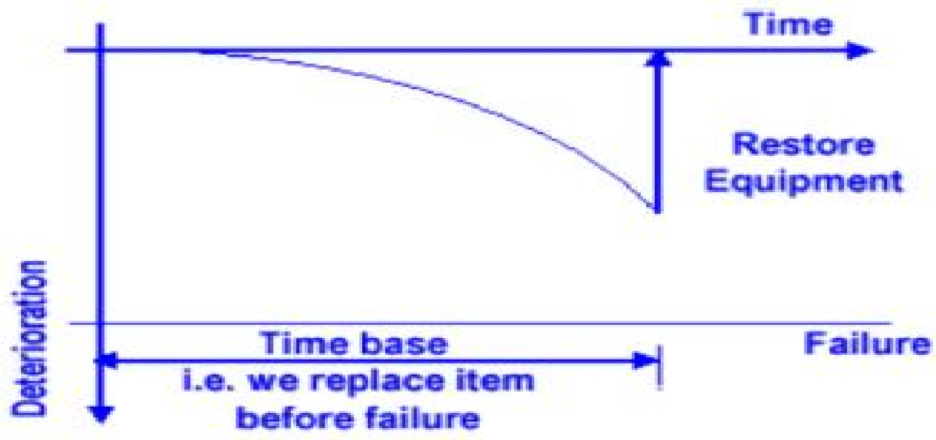


Figure 2.2*-Time Based Maintenance*

The advantages of TBM are:

1. Reduction of Breakdowns
2. Efficient use of labor maintenance
3. Planned maintenance activities

The disadvantages of TBM are:

1. The component lifetime is not completely used
2. Maintenance is performed invasive and could be unnecessary

2.1.4 Hit Based Maintenance

The HBM is similar to TBM but it consider the effective use of component (km,cycle,hours). The HBM is not always applicable because many times the specifications of suppliers are expressed in term of and time and for this reason is not possible to organize the maintenance only with the consideration of the use of each component.

The HBM depend from the machine and use the criteria of number of hits or number of movements.

2.1.5 Condition Based Maintenance

The CBM (figure 2.3) permit maintenance on each single component can be made in time, before breakdown happens. This method is possible if you are able to understand the symptoms that advise the breakdowns. For doing CBM, you need to do some measurements in order to understand the degradation of components.

Normally there are five class of machines signals:

- Acoustic and vibration emissions
- Thermal emissions
- Emissions due to cooling and lubrication flow
- Emissions about energetic consumption
- Emissions with effect on product
- Lubricants and coolants contamination

To understand the root cause are necessary more deep analysis. CBM is applicable if the cost of each single inspection is less than preventive activity of TBM and if the cost of the latter is less than BDM.

The advantages of CBM are:

1. Maximizes the availability of facilities improving the lifetime of components
2. Not expensive inspection with the use of 5 senses
3. Maintenance can be planned
4. Spare parts can be supplied promptly

The disadvantages of CBM are:

1. Specific tools and skills (vibration analysis, thermography and analysis of oils
2. Requires a good knowledge of the machine and its failures
3. Procedures must be chosen with proper care
4. There is the necessity of a period of time to build up the trend

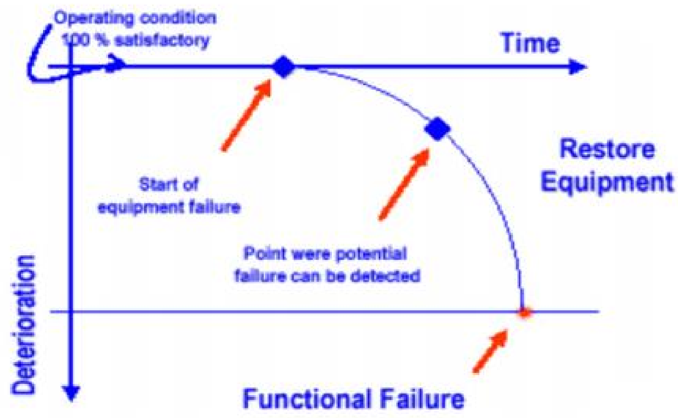


***Figure 2.3**-Condition Based Maintenance*

2.1.6 Corrective maintenance

The aim of CM is improving machine's maintainability and reliability. It is not a type of maintenance but is an approach to follow during the maintenance activities in order to improve the features of the machine with the modifications of the equipment.

The advantages of CM are:

1. Modification of equipment can be economic and functional
2. A serious or recurring problem can be solved finding the root cause

The disadvantages of CM are:

1. The real cause of the problem may be misunderstood
2. Some proposed changes may be expensive
3. Machine could have any improvement despite the application of CM
4. Solving a problem in one area can overload and cause problems in another
5. Unexpected problems can arise due to the change

To choose the correct maintenance strategy there are two important sources of costs have do be considered;

1. Manufacturing costs
2. Production costs

2.1.7 Inspection and repair

With inspection and repair (figure 2.4), we do periodical inspections to the components of machines; thanks to the inspections, we can know if the component it is ok or not. This type of maintenance is a sort of mix between TBM and CM:

- It is similar to TBM because the inspection is periodical
- It is similar to CM because after inspections we have to choose if the component needs maintenance

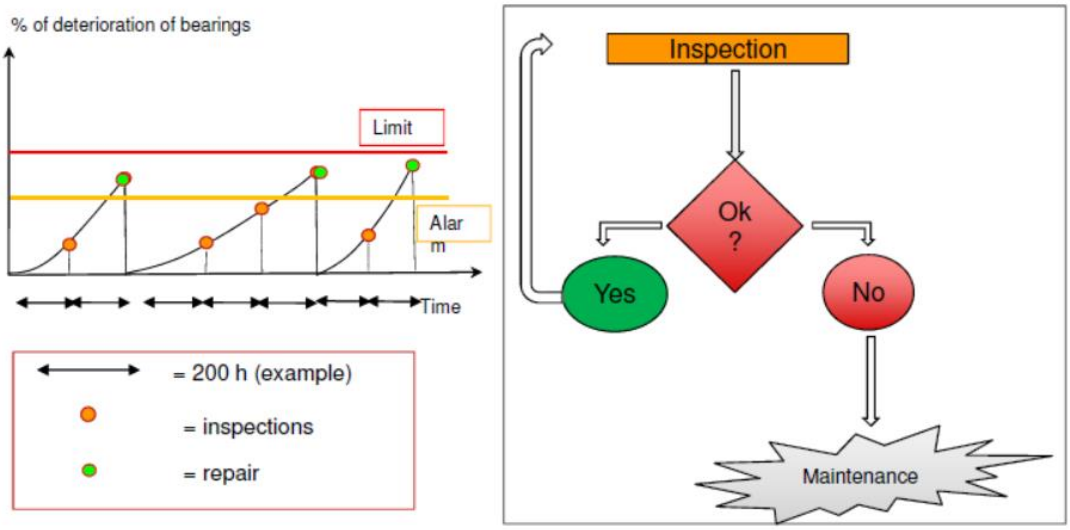


Figure 2.4*- Inspection and repair*

In the graph below (figure 2.5), we can find the relationship between complexity (in term of technical tools and knowledge) and maintenance costs:

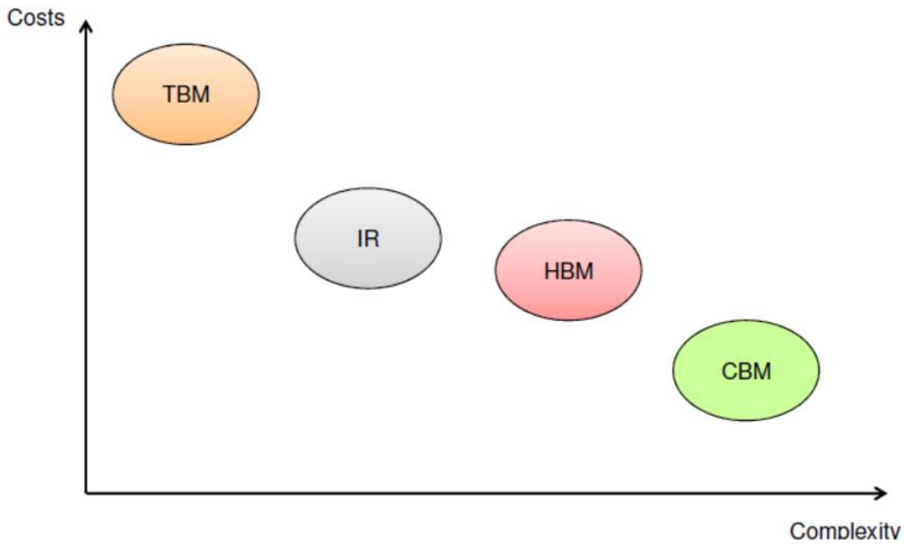


***Figure 2.5**- Maintenance costs*

2.2 Classification of the machines

The classification of machines depends on the subject and on the level of countermeasures. The countermeasures depending on the kind of approach is adopted.

- In the **reactive phase** countermeasures are realized after one event and there are high losses that drive machine classification. In this phase the machine classification came from the Cost Deployment
- In the **preventive phase** countermeasures realized on the base of past experience
- In the **proactive phase** countermeasures aimed to avoid that an event happens on the base of a theoretical risk analysis. In this phase and in the before phase the classification is based on P.Q.C.D.S.&M.

Moreover, thanks to the Pareto diagram is possible (figure 2.6) to classified machines in four class:

1. **AA**: Most critical machines, covering 50% of breakdown losses due to lack of professional maintenance;
2. **A**: Critical machines covering up to 70% of the BD losses;
3. **B**: Less critical machines, covering up to 90% of the BD losses;
4. **C**: Machines with lowest priority, covering the last

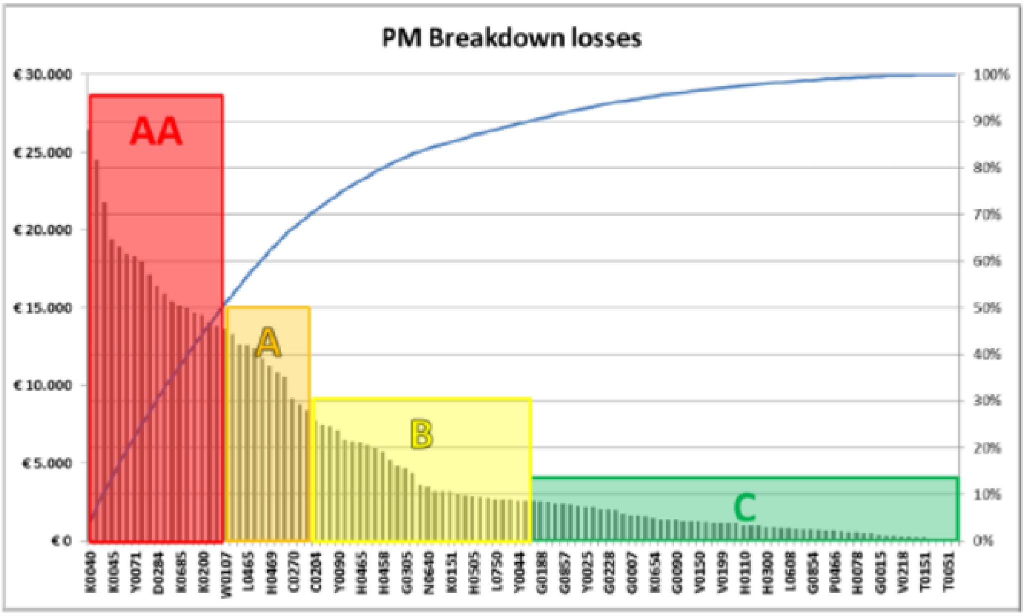


***Figure 2.6**- Pareto diagram and reactive classification*

PQCDS&M is a method to classify the machines based on six main criteria

- **P**: Impact on the production in case of breakdown
- **Q**: Impact on quality in case of breakdown
- **C**: Impact on costs in case of breakdown
- **D**: Impact on delivery of part of a possible machine failure
- **S**: Impact on safety & environment in case of breakdown
- **M**: The spirit of participation of people (Moral)

Grade	Production (P)				Quality (Q)		
Description	Impact on Production of a possible Machine Failure				Impact on Quality of a possible Machine Failure		
Item	Machine usage	Back-up possibilities	OEE	Impact on Plant	Type of complaint	Detection of the defect	Cost of Rework / Scrap
Guidelines for scoring	3 shifts = 25 2 shifts = 15 1 shift or occasionally = 5	No = 15 Yes, but not completely = 10 Yes, completely = 0	<75% = 35 76%-90% = 15 >91% = 0	Closing of Plant = 25 Production loss = 15 No impact = 0	Client level = 50 Internal level = 35 No complaints = 0	At the customer = 35 At final check = 15 In the line = 5	>250€/piece = 25 100-249€/piece = 15 <99€/piece = 5
Max	25	15	35	25	50	35	25
Min	5	0	0	0	0	5	5

***Figure 2.7**- Preventive Classification P&Q criteria*

Cost (C)				Delivery (D)	Safety and Environment (S)		Morale (M)
Impact on Cost of a possible Machine Failure				Impact on delivery of parts of a possible Machine Failure	Impact on Safety and Environment of a possible Machine Failure		Number of kaizen done
Cost to maintain basic conditions (AM)	Cost to maintain basic conditions (external companies)	Maintenance cost (Breakdowns)	Energy Loss	Existence and size of buffer	Safety risk in case of Breakdown	Environmental impact in case of Breakdown	Kaizen number done at the beginning of the activities
>1000€/month = 20 501-999€/month = 15 <500€/month = 5	>1000€/month = 15 501-999€/month = 10 <500€/month = 5	Frequent stops, High cost = 40 Few stops, basic cost = 20 No impact = 0	High impact = 10 Medium impact = 5 Low impact = 0	No buffer = 50 Buffer less then 1 day = 15 Buffer of 1 day or more = 0	Risk of mortal incident = 70 Injury risk = 50 First Aid risk = 30 No risk = 0	High Impact = 30 Medium impact = 15 No impact = 0	>3 times = 0 >2 and <3 times = 10 ≤2 times = 25
20	15	40	10	50	70	30	25
5	5	0	0	0	0	0	0

Figure 2.8- *Preventive Classification CDS&M criteria*

A machine stoppage is classified according to the time of failure, so we can define two types of stoppage:

1. Breakdown: the stoppage time lasts more than 10 minutes
2. Minor Stoppage: the stoppage time lasts less than 10 minutes

The main causes of machine breakdown are:

- Deterioration
- Excessive stress
- Insufficient robustness

The deterioration is the decrease of physical strength and capability of the machine during the passing of time. It depends from lack of basic condition (cleaning, lubrication, etc), insufficient skills of the operators, externals influence due to environmental factors such as temperature and humidity, off design operating condition (speed, pressure)

The excessive stress due to off design operating conditions, lack of restoration of anomalies, insufficient skills of operators and externals influence due to the environmental factors such as vibration.

Insufficient robustness comes from the fact that the machine doesn't resist to the stress and forces applied in normal working conditions due to weak design of the machine, external influences due to environmental factors and lack of skills at manufacturing stage.

2.3 Lubricants and spare parts management

Another important problem in the plant is the management of spare parts and material. Proper management of spare parts have to satisfy two basic needs:

1. Have the component in warehouse
2. Provide quickly to purchase spare parts

To maximize the levels of stocks of spare parts you can:

- Use appropriate techniques to forecast trends in stock
- Framework agreements with suppliers for the purchase of spare parts with low led time

The correct management of spare parts is made of seven steps:

1. Step1: Establish spare parts management policy
2. Step2: Put spare parts in order
3. Step3: Determine quantity of each spare parts to keep
4. Step4: Establish visual management system at the spare parts warehouse
5. Step5: Establish a computerized spare parts management system, synchronized with TBM and CBM
6. Step6: Standardize spare parts as much as possible with EEM

To ensure a correct management of lubricant purchasing, it is necessary to focus attention on some stages:

- Lubricants specifications: are essential to identify the optimum lubricant for application
- Criteria of purchase: lubricant purchase process is much more than a decision based on price, because they should be chosen also according with technical performances
- Involvement of other functions: Production, Maintenance and Engineering are the figures that should be involved in all issues related to lubricants
- Purchase planning: lubricants have deadlines and must be purchased in quantities as much as possible consistent with their actual use
- Supplier evaluation
- Supplier audit
- Value added services

Ensure that the facilities are not a source of contamination of lubricants.

- Filtering: adequate filtering system to prevent the entry of dust and moisture
- Unit of inspection: inspection of the equipment lubricants must be made using the most suitable PPE’s to check for contamination
- Monitoring: monitoring conditions of the facilities (temperature and pressure)

2.4 Pillar team organization

One of the most important activity is the organization of the project team, which is performed by the pillar leader of PM in collaboration and with the support of the Management Team and Plant Manager. The activity consists of three main macro-phases:

- Choosing the pillar team
- Evaluation of competence of the team
- Gap analysis, training and collecting the necessary skills

The pillar team is composed by:

- PM pillar leader: coordinates pillar's activities and develops and controls the projects of PM according to the general strategy of WCM
- Unit managers: ensure the commitment on projects to support the PM and pillar leader in planning and management activities
- PD pillar leader: support pillar leader to identify needs, in terms of know-how, and in generation of training activities plans
- CD leader: support pillar team leader and PM in the choice of priorities
- FI pillar leader: supports the pillar leader and the projects of PM in resolving specific issues
- AM pillar leader: support pillar leader in managing the specific training and coordination of the team in the development of PM

After the creation of the Pillar team is important to value the competences of team members with radar charts which represent a tool map competences of Pm pillar members (figure 4.9). These competences changes as pillar activities move from reactive phase to preventive and after to proactive phase, where:

1. Reactive phase: Step 1, Step 2 and Step 3
2. Preventive phase: Step 4 and Step 5
3. Proactive phase: Step 6 and Step 7

To develop a project team of PM it is necessary to evaluate skills both in terms of know-how of the pillar and process or equipment. The evaluation process follows the following pattern:

- Identify skills needs on the PM tools and steps of the pillar
- Definition of the minimum of competences required
- Addition of a range of the level recorded for each team member into the radar chart or similar tool

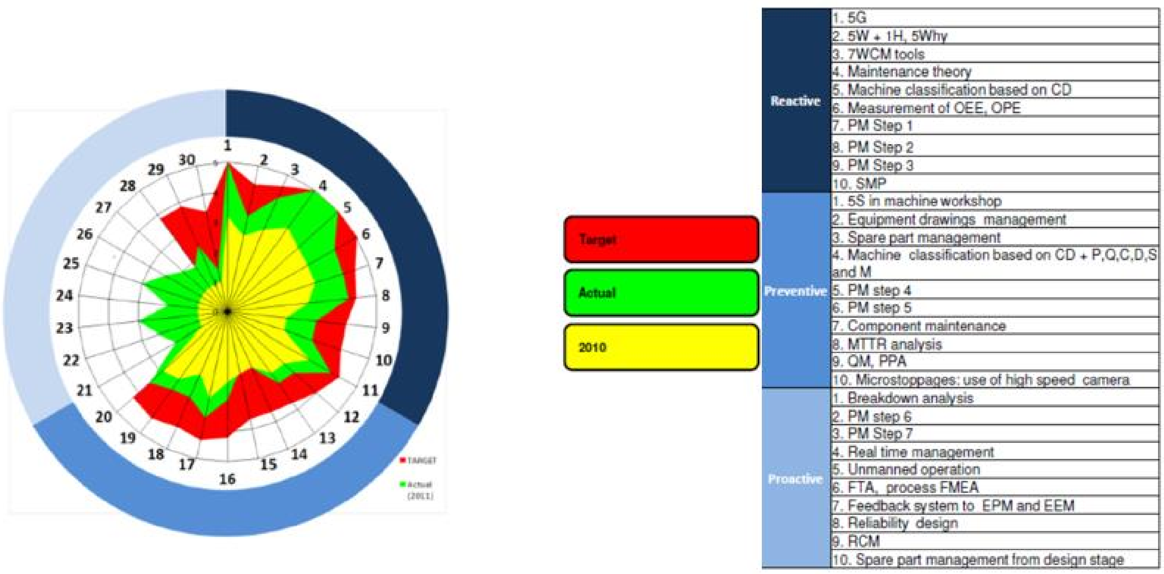


***Figure 2.9**- Radar chart*

The strategy of the pillar defines the guidelines of the activities and the operation level, that consist in a sort of transformation of long-term plans in detailed and immediate actions, such as the opening of management of projects for maintenance training in the specific areas of the plant. The priority of intervention is chose thanks to the classification (AA-A-B-C) or cost deployment.

2.5 The seven PM steps

The PM pillar is based on a seven steps program to obtain a continuous improvement. The PM (figure 2.10) steps are:

1. Elimination of forced deterioration and prevention of accelerated deterioration
2. Breakdown analysis
3. Establishment of maintenance standards
4. Countermeasures against weak points of the machine and lengthened equipment life
5. Build a periodic maintenance system
6. Build a predictive maintenance system (trend management)
7. Maintenance cost establishment of planned maintenance system

With this seven steps the pillar activity move from reactive to preventive up to proactive phase.

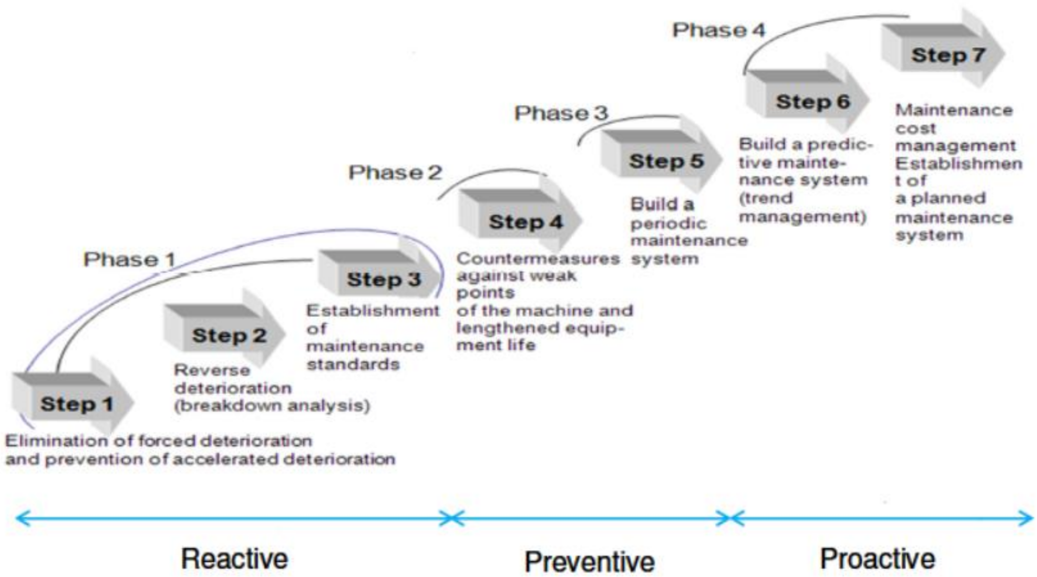


Figure 2.10*- PM steps*

2.5.1 STEP 1: Elimination and prevention of accelerated deterioration

The step 1 consist of:

- Definitions and indicators
- Professional preparation of maintenance system

- Elimination of deterioration

First of all is important to understand the performances of the equipment which are evaluated in term of equipment efficiency, labor efficiency, materials and energy.

To understand these performances is necessary to follow and analyze trends and values of KPIs (key performance indicators) and KAIs (key activities indicators).

The professional maintenance KPIs are:

- Number of breakdown
- MTTR (mean time to repair)
- MTBF (mean time between failure)
- OEE (overall equipment effectiveness)

The professional maintenance KAIs are:

- Number of EWOs
- Maintenance activities stratification
- Number of Kaizen in maintenance
- TAGs closed by maintenance

Indices	**Used to measures**	**How to calculate**
MTTR	Maintainability	$\frac{total\ repair\ time}{total\ numbers\ of\ repairs}$
MTBF	Reliability	$\frac{total\ rintime - downtime}{number\ of\ breakdowns}$
OEE	Effectiveness	$\frac{time\ to\ produce\ OK\ parts}{planned\ production\ time}$

The MTTR is evaluated in the following way:

$$MTTR = \frac{\sum_1^N TTR_i}{N}$$

Where:

- TTR= time to repair every breakdown (reparation time figure 4.11)
- N= number of breakdown in the considered time

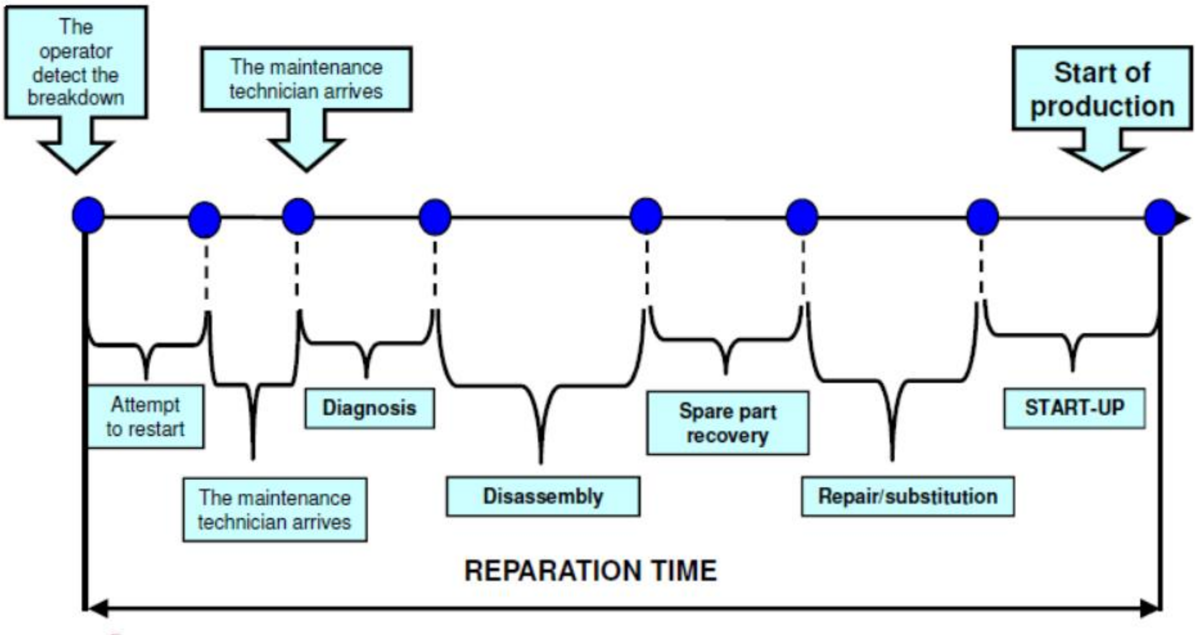


Figure 2.11- *Reparation time*

The MTBF is calculated as:

$$MTBF = \frac{\sum_{2}^{N}(T_P - T_B)}{N}$$

Where:

- T_P=time of planned production
- T_B=time of breakdown
- N=number of breakdowns

The OEE is the overall efficiency of the equipment (figure 2.12)

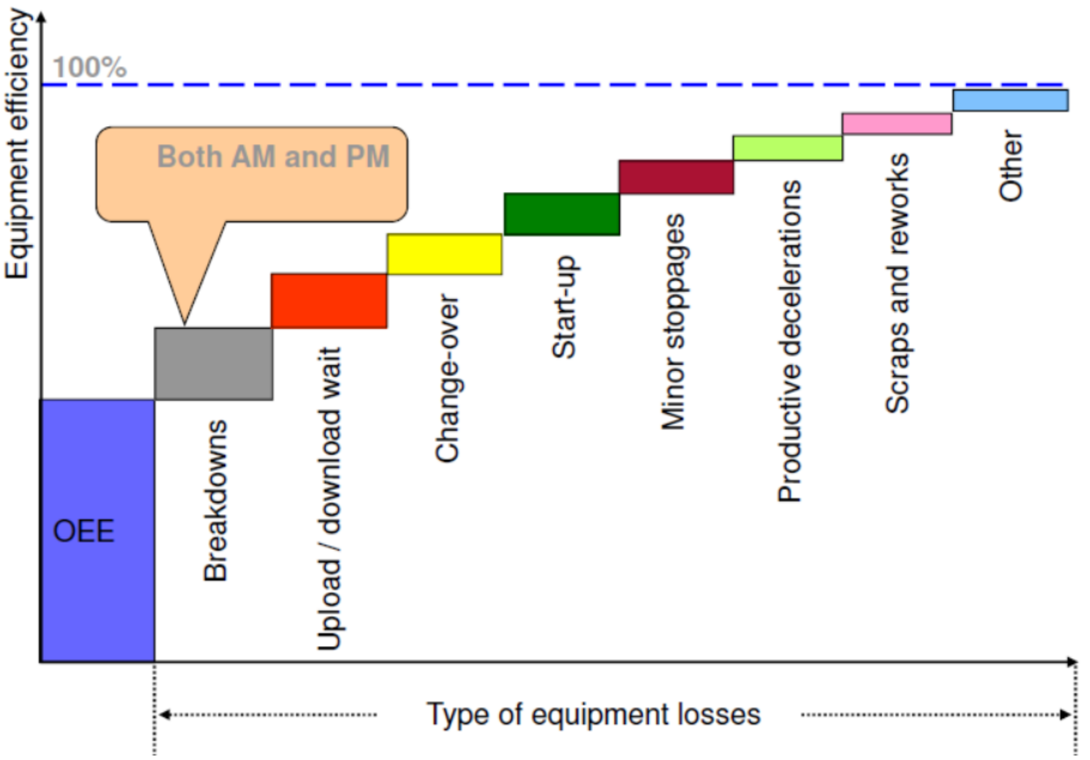


***Figure 2.12**- OEE definition*

The OEE is calculated as the product of the four indices of efficiency

$$OEE = (M * A * P * Q) * 100$$

Where:

- Q: losses due to quality of the product
- P: losses due to performance of the equipment
- A: losses due to availability
- M: losses due to other causes

$$M = \frac{PPT - T_{otherLosses}}{PPT} = \frac{RAT}{PPT}$$

$$A = \frac{RAT - T_{downtime}}{RAT} = \frac{OT}{RAT}$$

$$P = \frac{OT - T_{speedlosses}}{OT} = \frac{NOT}{OT}$$

$$Q = \frac{NOT - T_{quality}}{NOT} = \frac{FPT}{NOT}$$

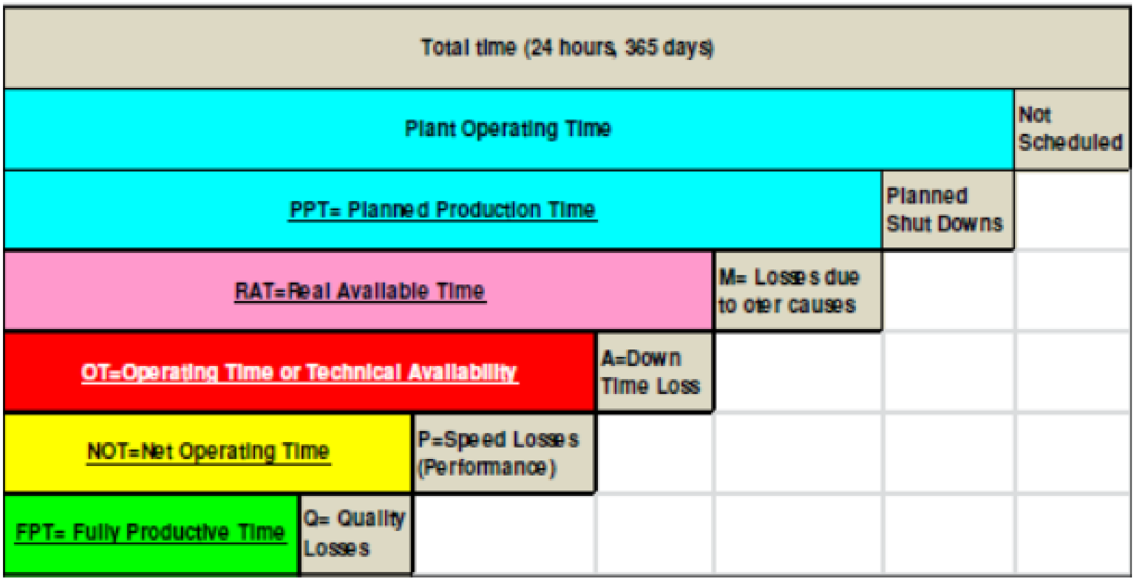


Figure 2.13- *OEE indices*

After the evaluation of these KPIs you have to improve them with the shortening of MTTR through the upgrading of the skills of maintenance people and the improvement of management spare parts and by facilitating the access to facilities. At the other hand, we have to improve the elongation of the MTBF through the maintaining of the basic conditions (AM), a correct failure analysis and with a cyclical maintenance plan.

After the evaluations of the KPIs it is important to prepare the professional maintenance strategy through the build of the machine ledgers. The machine ledger is "the bible" of PM pillar, where are listed all component of the machine divided in group and subgroup. A component is the smallest element that can be replaced in case of maintenance operation. The components are classified in different classes:

- A: when the component breaks down the equipment stops
- B: when the component breaks down the impact is limited
- C: when the component breaks down the equipment doesn't stop

For each component it is necessary to define the correct type of maintenance. The planned maintenance activities come from breakdowns analysis (EWO), TAGs and experience on similar machines.

For all maintenance activities, we should give the following setting:

- Group where the activity is applied
- Description of the activity
- Durations
- Frequency
- Machines status: working or stopped

The machine ledger is also shows the type of maintenance. The following figure represent a proposal of machine ledger (figure 2.14):

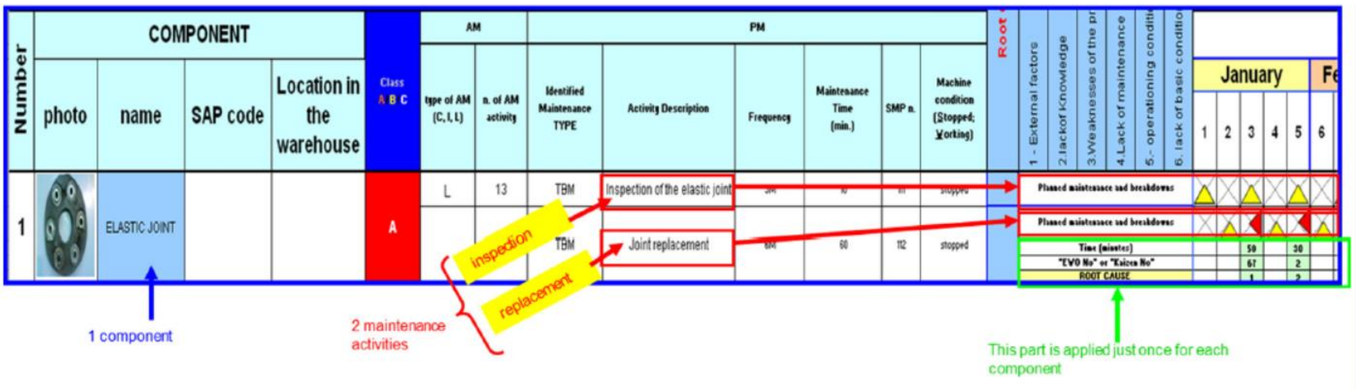


Figure 2.14- *Machine ledgers*

After preparations of PM strategy, the step 1 aims to the elimination of the deterioration. When a machine is neglected, the deterioration increases during the passing of time, it spreads out in the area and it facilitates the occurrence of faults for other components. Situations out of control can lead to the creation of concatenated problems.

Main cause of deterioration is dirt that can cause:

- Breakdowns
- Quality defects
- Acceleration of deterioration
- Speed loss

There are two forms of deterioration:

- Natural degradation: normal deterioration that occurs with the correct use of equipment and basic maintenance activities
- Accelerated or forced deterioration: linked to human factors, with a growth bigger than natural degradation; these are the result of maintenance activities neglected like cleaning and lubrication; it can also be the result of natural decay.

To stabilize the MTBF it is essential to eliminate the accelerated deterioration through:

- Restoration of deterioration
- Maintaining the basic conditions
- The elimination of the forced deterioration

These activities go, inevitably, through the support during the AM first three step.

The stabilization of the MTBF is useful to make it more stable and so more predictable; knowing in a statistical way the distribution function of MTBF (mean value and variance), is possible to know the right period of replacement of components. Knowing the statistical (mean value and variance) as a distribution of the MTBF, we can define the period of more appropriate replacement of the component.

The objective is to:

- Increase the average value
- Reduce the variables

For this purpose, it is necessary to remove the accelerated deterioration through:

- Restoration of deterioration
- Maintaining the basic conditions
- The elimination of the forced deterioration

In this phase is important the correlation between AM and PM activities.

2.5.2 STEP 2: The breakdown analysis

This steps aims to:

- Avoid the recurrence of serious failures and reduce the occurrence of micro-stoppages
- Reduce anomalies and defects of the product due to the condition of the equipment
- Develop techniques for problem solving and breakdown analysis

The process of breakdown management can be described by a cyclic flow in which eight phases are underlined:

1. The occurrence of the breakdown
2. The identification of possible causes
3. The investigation and repair of the breakdown with a return to production
4. The documentation of the breakdown with physical evidence (photos, 5W & 1H, Quick Kaizen)
5. The review of 5W & 1H to define / confirm the action
6. The implementation of the technique of problem solving "5 why's"
7. The selection and testing of countermeasures
8. The analysis of trends and subsequent standardization of the countermeasure (if feasible).

To analyse the failures is necessary to establish a TAGS collection system of damaged parts in order to provide physical evidence to support research of possible causes. The TAG must be attached to the broken component and kept in a place set for a defined period. To solve the problems of breakdowns is necessary to have it physically and analyse the damaged or broken part to clearly see the damage.

The most important tool for PM pillar is the EWO (emergency work orders) which allows operators to indicate any element that requires maintenance on machines. The EWO is divided in different parts.

First of all the EWO is featured by the description of the actions done and in case of difficult representation with a picture to explain the actions have to be shown and with the description of spare part. After the usage of 5W + 1H (figure 2.15) approach, which is compiled by the conductor of the machine with the management support, is useful to define the problem.

Analisi 5W + 1H		
Che cosa (what)	What was the machine doing?	
Quando (when)	Equipment Start up - Start shift - During the shift - End of Shift - After set up - Other	
Dove (where)	Subgroup, Component	
Chi (who)	Who detected the problem (maintenance, operator...) - Who are the people involved?	
Quale (which)	There were premonitory symptoms of the fault ? It happens in a particular condition ?	
Come (how)	What are the consequences of the fault on the machine ? (Compared to optimal operating conditions)	

Figure 2.15- *5W+1H*

The application of 5W+1H is necessary in order to define the root cause and for this reason than the operator have to insert the 5 whys analysis and check if they are the cause of breakdown or not. After that there is the stratification of the breakdown by root cause (figure 2.16). The division of the causes allows to identification of the pillar that has to solve the breakdown and make the improvement plan in order to avoid the occurrence of the issue again.

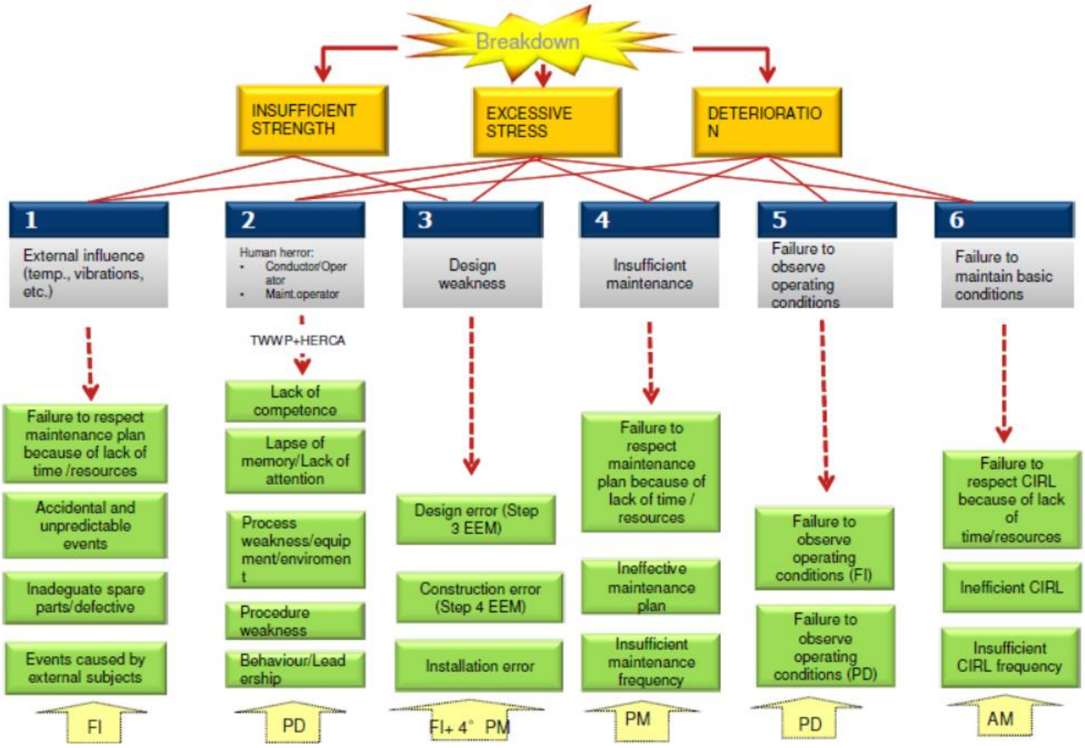


Figure 2.16- *The breakdown stratification by root cause*

In order to remember the breakdowns occurred on the machine, a register to note is needed:

- Number of emergency work orders (EWO)
- Data

- Issued by
- Type of problem;
- Root cause
- Immediate countermeasure
- Details of the countermeasure implemented
- Actions to support the countermeasures

2.5.3 STEP 3: Definition of maintenance standards

The aim of the step 3 is:

- Define the contents of the maintenance standards
- Prepare the standard procedures for periodic maintenance
- Schedule maintenance activities
- Monitoring performance
- Identify countermeasures

We have to define and implement procedures:

- Substitution
- Lubrication
- Inspection
- Settings and adjustments
- Tests (environmental and safety controls)
- Calibration
- Mechanical overhaul
- Electrical overhaul
- Hydraulic overhaul

With a definition of periodical maintenance system are organized periodic replacement of worn parts. The aims of replacement activity are:

1. Elimination of deterioration (STEP 1 of PM)
2. Reduction of breakdown statistic variance (STEP 1+ STEP2 of PM)

To define the correct specifications for the implementation of standard maintenance activities we have to trust in both the information received from the manufacturer and the experience and the knowledge of operators.

In the specifications for the maintenance standard we should define:

1. What maintenance activities are required
2. When the activities must be carried out (frequency and duration)
3. Criteria and parameters
4. How the activities carried out
5. Who should carry out the activities

For these reasons in this phase are developed the Standard Maintenance Sheet (SMS) which consist in maintenance instruction, described in details step by step with a low utilization of visual, and the

Standard Maintenance Procedures (SMP) which is related to SMS as further detailed description of its specific activities with the use of visual (photos or sketches).

After step 3, analysing losses curve due to breakdowns (figure 2.17) against maintenance costs, it is clear a trend inversely proportional of two curves:

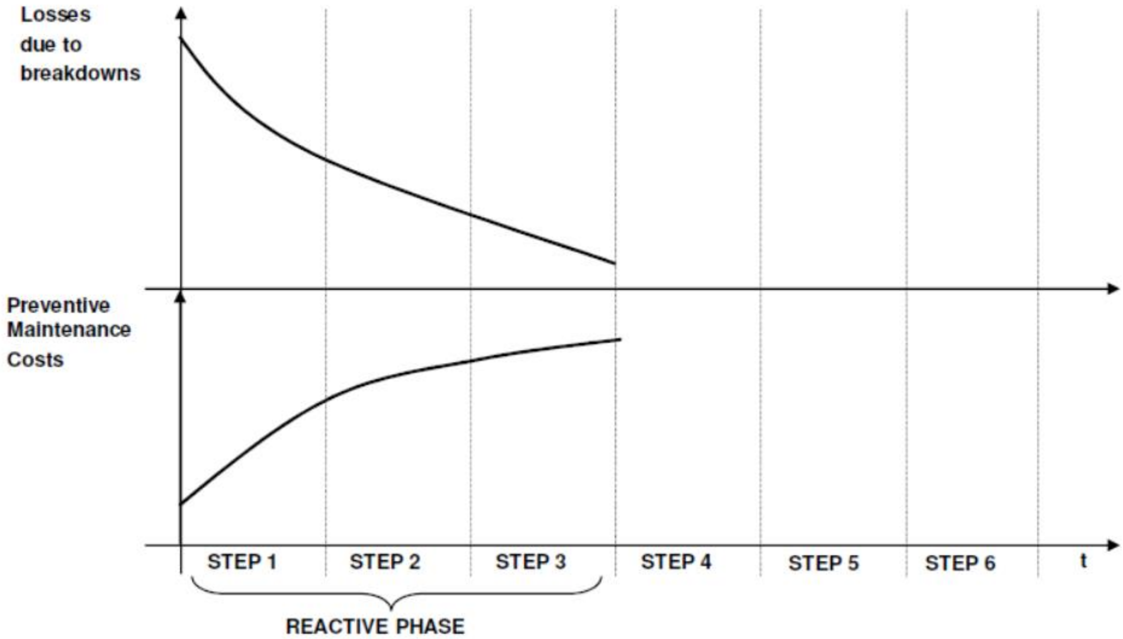


Figure 2.17*- Maintenance costs*

2.5.4 STEP 4: Countermeasures against weak points of the machine and lengthened equipment life

Once identified the primary component to work on, you have to choose where the focus improvement has to start. In the first three steps were necessary to attack the deterioration as a cause of breakdowns while in this step we must also consider the other two causes: the excessive stress and the insufficient robustness.

To minimize the probability of breakdown on the component and to extend the average life we works in two ways:

1. Strengthen the component by increasing the loads permitted on the project (focused improvement on the component)
2. Strengthen the process by allowing the component to work with lower medium-stress distant from the design average level admitted (focused improvement on the process)

The purpose of the step is to lead focused improvement activities in order to correct the deficiencies and to extend the useful life of the component (figure 2.18).

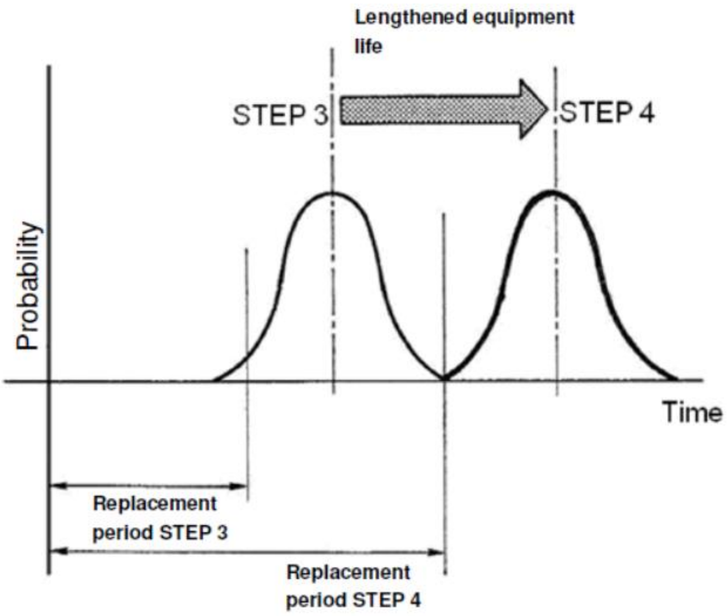


Figure 2.18- *Step 4 aim*

At the end of step 3,we reach the maximum level of costs of maintenance with an excessive cost of planned maintenance which is called over-maintenance. When the equipment shut down to allow maintenance activities we generate downtime losses. Actually, not all equipment downtime due to planned maintenance stop must be considered loss but only the part considered as over maintenance. For this reason, the steps from 4 to 7 aims to reduce the cost of over-maintenance which is considered about 30-40% (figure 2.19).

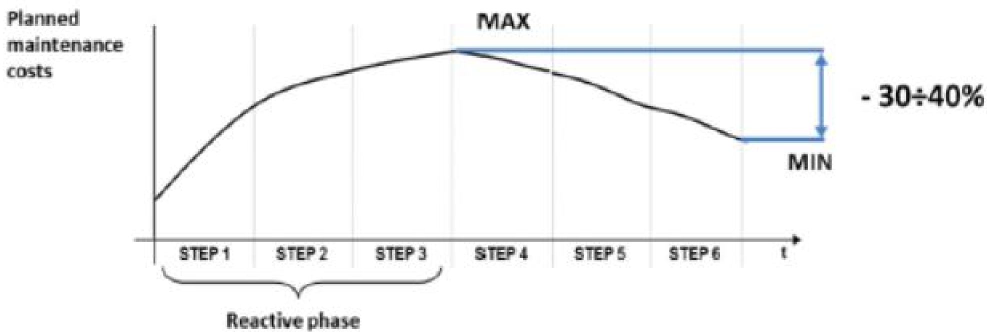


Figure 2.19- *Maintenance costs reduction*

The cost of maintenance is evaluated in the following way:

$$COST_{Maintenance} = COST_{SP} \cdot N_R + COST_{LB} \cdot H \cdot N_R$$

Where:

- $COST_{SP}$: cost of spare part
- N_R: number of replacement

- $COST_{LB}$: cost of labour
- H: hours for intervention

With the step 4 we work in order to:

- Reduce the number of replacements through the extension of component life
- Reduce time to replace (H)

In the step 4 the preliminary activity is to attack first the maintenance labour cost of the total cost of the component, and after reducing substantially attack component costs by improving the lengthening of the lifetime. The expected result of focused improvement on the component or process is to lengthen the average life of the component and thus enable a maintenance plan with greater frequency than before. The next step is standardization with MP info. In the step 4 maintenance costs curve changes the increasing trend of reactive phase (first 3 step) and, thanks to lengthening activity of average life of components and hence to reduction of cycles frequency, starts decreasing (figure 2.20).

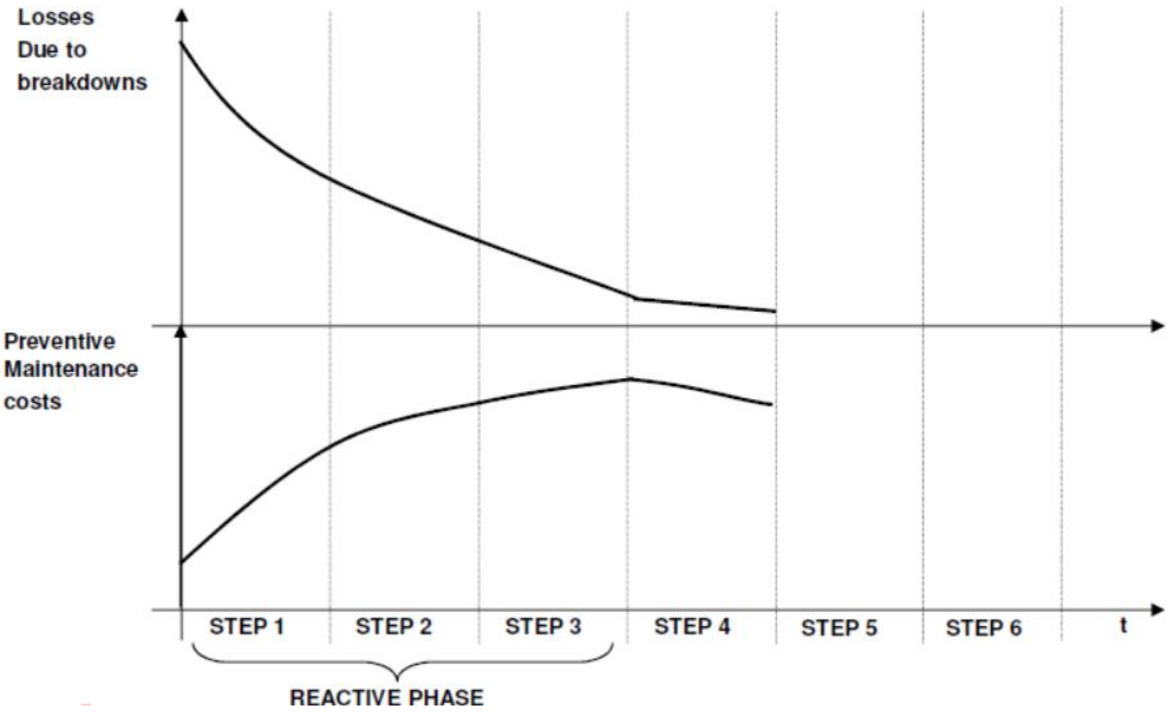


Figure 2.20- *Maintenance costs after step 4*

2.5.5 STEP 5: Build a periodic maintenance system

Step 5 activities are focused on preventive maintenance cost reduction, which have already been attacked and partially reduced in step 4. The step 5 following the ECRS logic (Eliminate Combine Reduce Simplify) consist in:

- The frequency revision of Time Based Maintenance (TBM) activities, established through step 1,2,3 and 4
- Transfer the maintenance activities from PM to AM
- Change TBM in HBM

From step 1 to step 3, PM has promoted high frequencies of TBM activities in order to reduce breakdown losses as quickly as possible, even if maintenance costs could increase. This approach generated over-maintenance that is a loss due to a premature replacement of the component and a limited utilization of its life (figure 2.21).

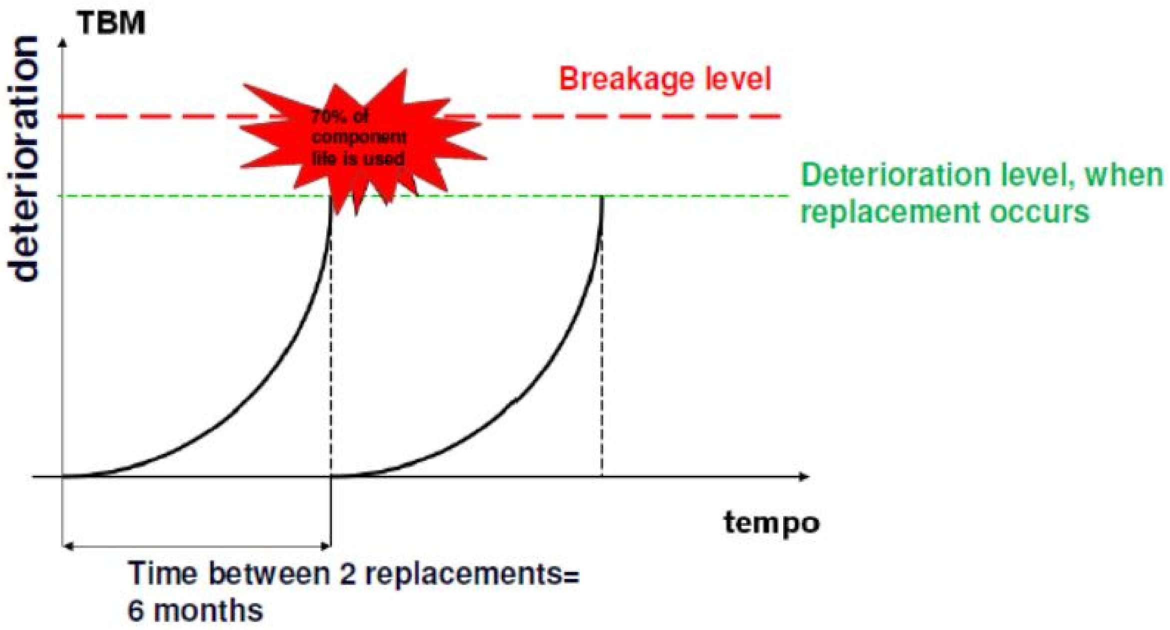


Figure 2.21- *TBM approach*

After step 4 activities, maintenance costs are revised the Pareto diagram is used for choosing priorities at the beginning of step 5, that are still those components with the highest preventive maintenance costs (manpower and spare parts).

In order to reduce replacement frequencies, we can proceed as follows:

- Identify the dimension of the component, representative of its deterioration
- Measure deterioration:
  1. if the component is accessible on the machine, establish periodical inspection (dimension measurement) between 2 replacements in order to follow up the deterioration and finally validate/reduce the replacement frequency
  2. If the component is not easily accessible on the machine, parameter is measured, when the component is replaced. Thus, we can verify if the component is still good or it could work for longer
- Revise frequencies: if measurements are positive, it means that component is not fully used and so replacement frequencies can be reduced

In step 5 maintenance costs keep decreasing, thanks to frequency optimization of maintenance activities (figure 2.22).

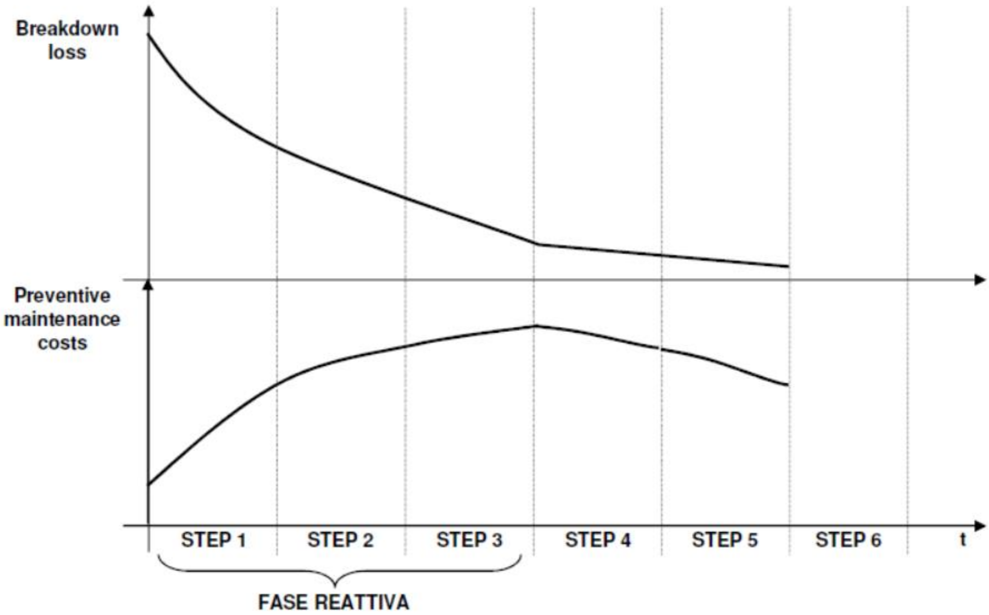


Figure 2.22*- Maintenance costs after step 5*

2.5.6 STEP 6: Creation of a predictive maintenance system

The aim of this step is:

- Extend the lifetime of component as much as possible
- Reduce maintenance costs
- Maximize the availability of facilities
- Improve quality
- Improve safety by preventing accident

In this step we move from TBM approach to CBM approach. In CBM, we try to maximize usage of components life. This is achieved by monitoring critical parameters of component, which speaks about its condition.

We have to estimate the value of over-maintenance costs for each category of components and after attack the highest value.

The step 6 activity is development in the following way:

1. Finding parameters to be monitored
2. Monitoring of parameters
3. Fixing limits
4. Changing component when reaches the limit

In step 6 is important to build a continuous monitoring system with the use of alarms in order to change the component when is necessary (trend management figure 2.23):

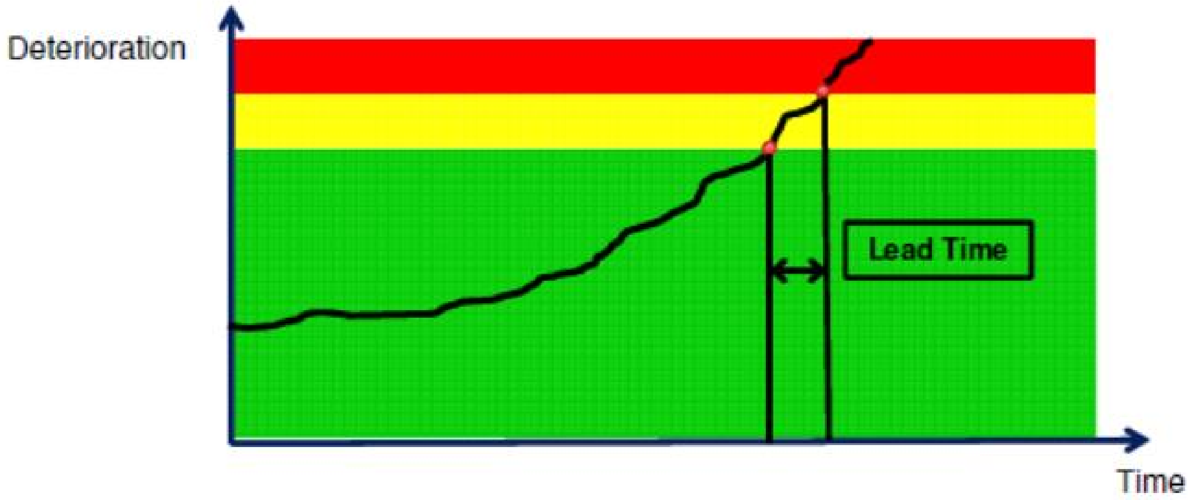


***Figure 2.23**- Trend Management*

Where:

- In the green zone the controlled variable is far from the maximum value admitted
- In the yellow zone the controlled variable is reaching the maximum value so it should be necessary an acoustic alarm
- In the red zone the controlled variable has reached or passed the maximum value admitted

The size of yellow zone depend from the lead-time and from the experience.

In step 6 maintenance costs curve, thanks to optimal exploitation of component useful life and hence reduction of cycles frequency, continues to decrease (figure 2.24).

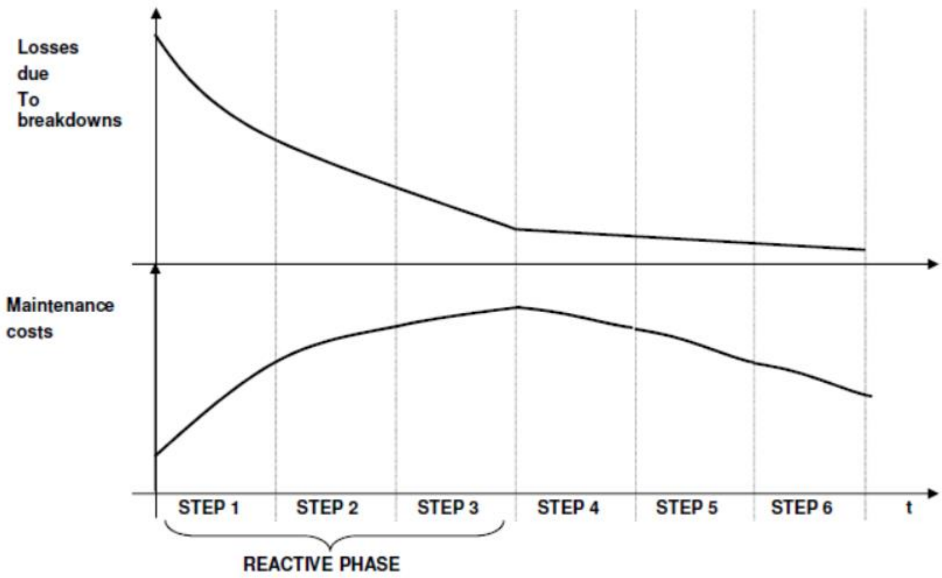


***Figure 2.24**- Maintenance costs after step 7*

2.5.7 STEP 7: Maintenance cost management

The activities of this steps consist of the evaluate cost savings : decrease in maintenance expenditures (reduction of overmaintenance) and improvement in distribution of maintenance costs:

- Warehouse advanced management: component standardization (EEM) and spare parts management with cheaper components
- Evaluate the planned maintenance system
- Evaluate maintenability improvement : periodic maintenance ratio, predictive maintenance ratio, MTTr
- CMMS (Computerized Manitenance Management System);

Another important activity of step 7 is the Financial Risk Deployment, which is used to support and drive decisions concerns Machine Obsolescence and potential losses. The Risk Assessment is used implement measures of effectiveness, providing the guidelines in terms of investments priority aimed to the risk elimination The risk index is affected by several factors and allows to define the critical issues and priorities to be attacked.

2.6 Evaluation of benefits/costs

The B/C ratio needs to understand if the project or the improvement costs are lower than the benefits obtained in one year. The benefit is the sum of all eliminated losses and cost avoidance. The cost is the sum costs to achieve the step. As a general rule if B/C>1 the project is rentable else the project is not rentable. The B/C evaluation if different for each step.

2.6.1 Step 1

The costs can be divided into two types:

- Running costs: these type of costs are considered as a subtractive term in the calculation of benefits because you have to spend money continuously to maintain the obtained status
- One shot cost: you have to spend money only one time and has to be considered as an additional term in the costs.

The cost of step 1 are composed of six items:

- l: hours of labour used in training multiplied by the hourly cost of labour
- m: hours of trainer (if internal) multiplied by the hourly cost of labour
- n: cost of company training (if external) and cost of teaching material
- q: cost to restore the basic condition, cost to reduce manpower and materials, cost because of missing production
- s: cost of cycles introduced during the step in progress, against the failures occurred

The benefits of step 1 instead depending from:

- x: delta recovered for loss due to deterioration failures
- y: delta loss recovered in time for CIL of the machine

The total costs of step 1 are:

$$C_{step1} = l + m + n + q$$

The total benefits instead:

$$B_{step1} = \frac{x \cdot 12}{t} + \frac{y \cdot 12}{t} - \frac{s \cdot 12}{t}$$

Where t is the time expressed in months

2.6.2 Step 2

The cost of step 2 are composed of five items:

- l: hours of labour used in training multiplied by the hourly cost of labour
- m: hours of trainer (if internal) multiplied by the hourly cost of labour
- n: cost of company training, whether external company
- q: cost of teaching materials
- s: cost to reduce the following root cause failures: FI plants cost improvements; PD hours training; PM cycle cost after failure analysis (calculated over 12 months); AM cost cycles introduced after failure analysis (based on 12 months);

The benefits depend from:

- x: delta loss recovered from breakdowns

$$B_{step2} = \frac{x \cdot 12}{t} - \frac{s \cdot 12}{t}$$

$$C_{step2} = l + m + n + q$$

2.6.3 Step 3

The costs and benefits of step 3 are expressed by the same voices of step 2, in fact:

$$B_{step3} = \frac{x \cdot 12}{t} - \frac{s \cdot 12}{t}$$

$$C_{step3} = l + m + n + q$$

2.6.4 Step 4

The cost of step 4 are composed of four items:

- l: cost of changes on the components and tools
- m: hours of labour used in training on new cycles multiplied by the hourly cost of labour
- n: cost of training (internal / external) for the new cycle
- q: cost of teaching materials for training on new cycles

The benefits of step 4 depending from:

- x: maintenance costs recovered lengthening the life of the component

$$B_{step4} = \frac{x \cdot 12}{t}$$

$$C_{step4} = l + m + n + q$$

2.6.5 Step 5

The cost of step 5 are composed of five items:

- l: hours of labour used in training on new cycles multiplied by the hourly cost of labour
- m: cost of training (internal / external) for the new cycle
- n: cost of teaching materials for training on new cycles
- q: cost equipment modifications (improvements to reduce the frequency)
- s: new tool cost (a new ammeter, contactless thermometer) or new tools that allow you to reduce periodical maintenance (TBM)

The benefits of step 5 are composed of individual items:

- x: maintenance costs recovered through the optimization of preventive activities (reduction in frequency cycle, reduce cycle times, etc.)

$$B_{step5} = \frac{x \cdot 12}{t}$$

$$C_{step5} = l + m + n + q + s$$

2.7 PM pillar in Driveline Plant

The PM pillar in Driveline Plant is at score 3 but in the next year will try to reach the score 4 following the program of the route map (figure 2.25)

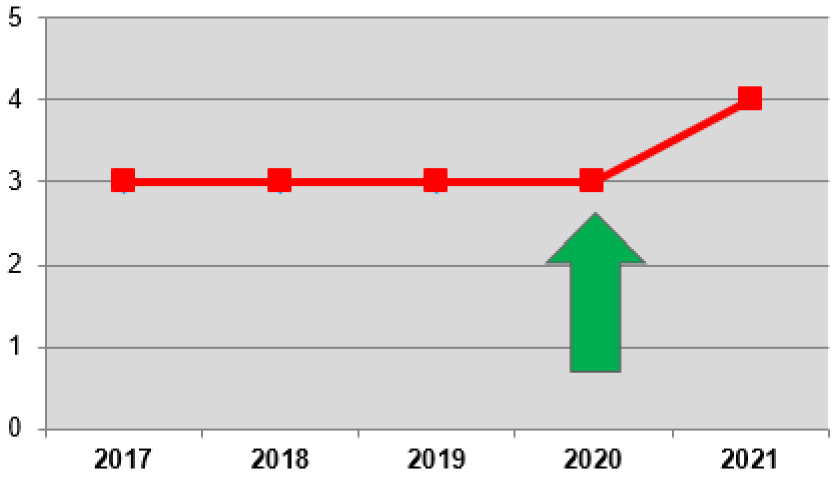


***Figure 2.25**- Score route map*

The PM team is composed in the following way:

Figure 2.26*- PM team*

Figure 2.27*- PM extended team*

In the figure 2.28 is represent the organization of the PM team:

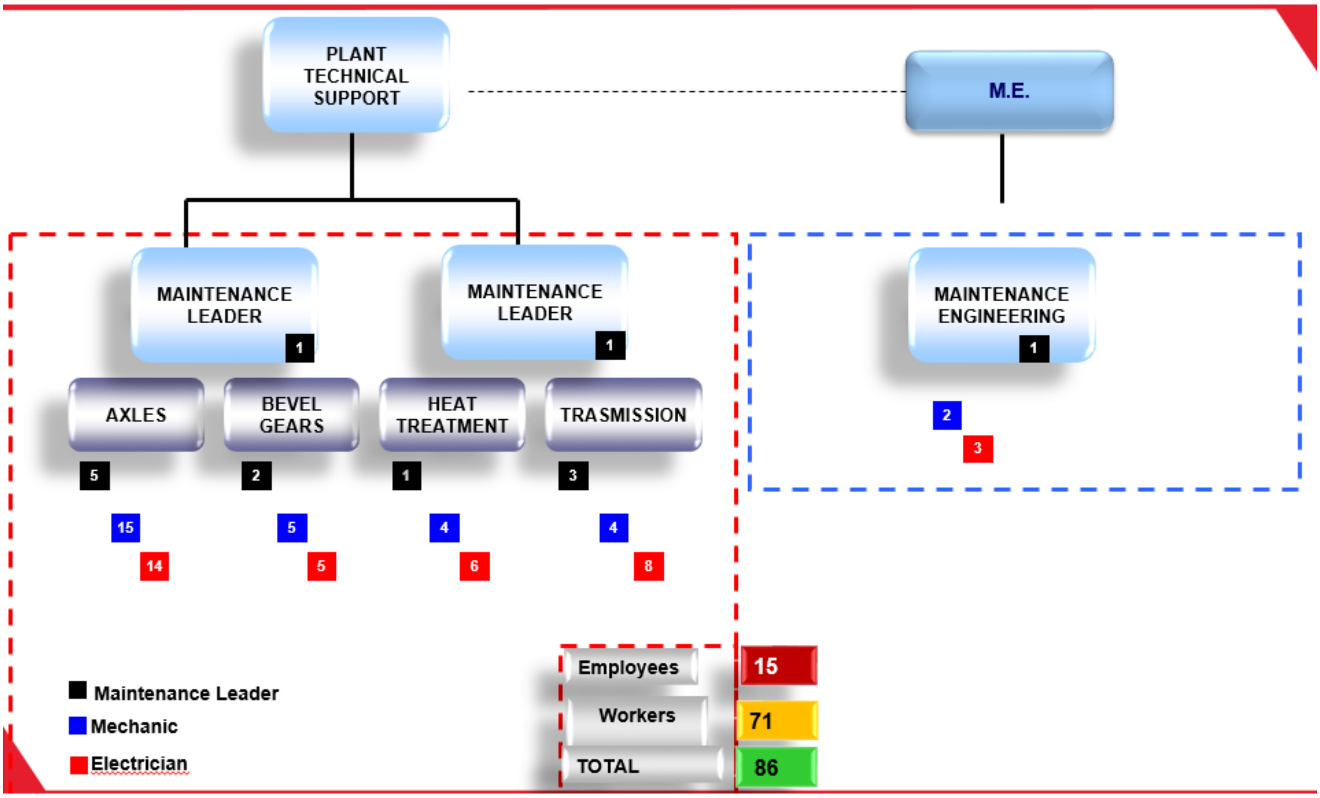


Figure 2.28- *PM team organization*

The WCM perimeter is composed by 302 machine, which are classified in the following way:

PM	December 2019							
Class	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Total
AA						13	10	23
A					16	6	7	29
B				7	42	13		62
C	8	32	31	80	29	8		188
Total	8	32	31	87	87	40	17	302

Espansione
% ≥ Step 3
76%
Profondità
% ≥ Step 4
48%

Figure 2.29- *PM machine classification*

3 The application of Professional Maintenance

In this chapter is represented the application of the professional maintenance pillar on the machines in the Driveline Plant.

We have analysed each phase of the continuous improvement method:

- The reactive phase: step 1-3
- The preventive phase: step 4 and step 5
- The proactive phase: step 6 and 7

3.1 Step 1-3

In the reactive phase, the aim is to attack the breakdown losses with a development of planned and scheduling maintenance in order to reach the zero breakdowns condition. In the first three steps, there is the reduction of breakdown losses with an increase of maintenance costs. Is reported below an example of application from the step 1 to step 3 in the Prawema machine.

3.1.1 The Prawema Machine

Initially was analysed the Pareto Diagram of breakdown losses of class C machine (figure 3.1) with the identification of the most expensive machine, which consist of the Prawema.

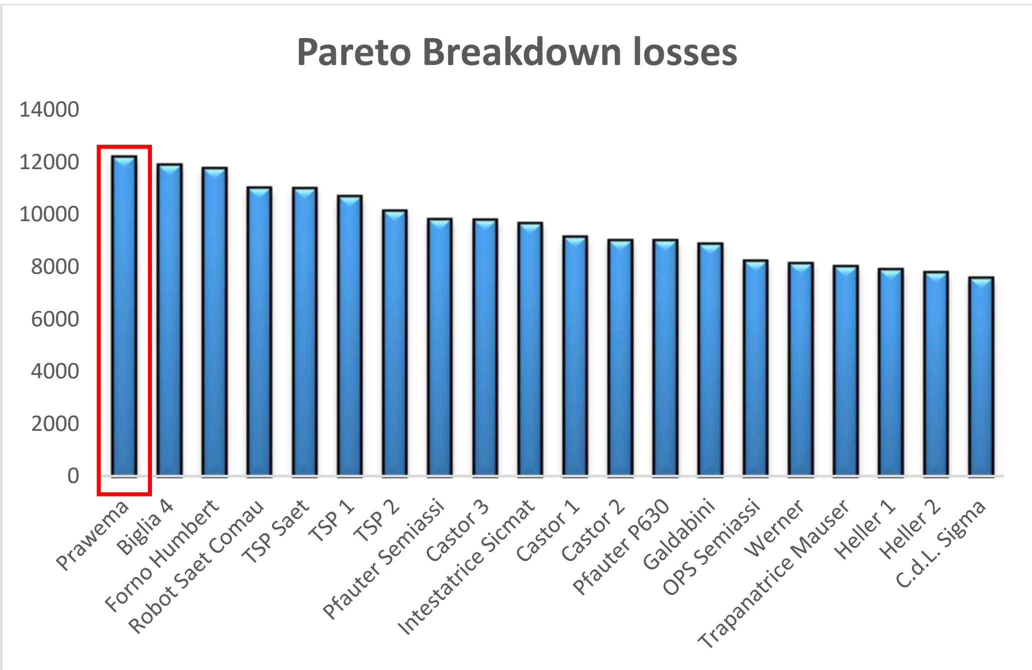


Figure 3.1 – *Pareto Diagram*

The Prawema is a grinding machine of the UTE 1.10 and is described in the following pattern

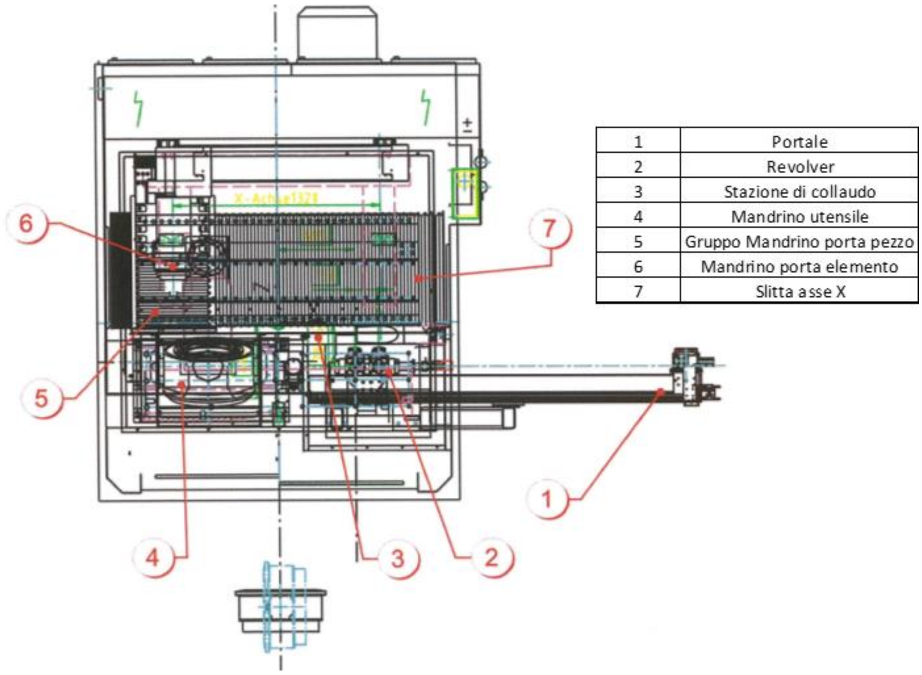


Figure 3.2 – *Prawema*

3.1.1 Step 1: eliminate the accelerated deterioration

This step is made in collaboration with the Autonomous Maintenance Pillar and starts from the analysis of the PM tags, which identify anomaly that can be solved by the maintenance people. After the analysis of the tags on the Prawema machine we obtain the following results (figure 3.3):

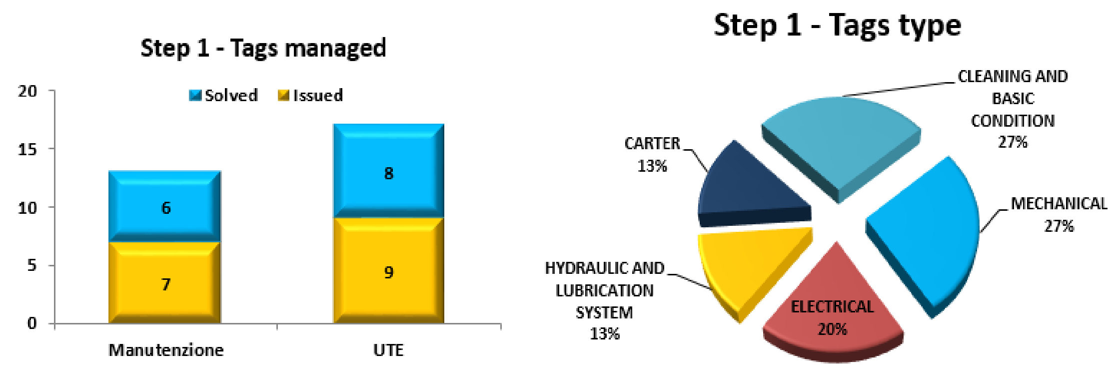


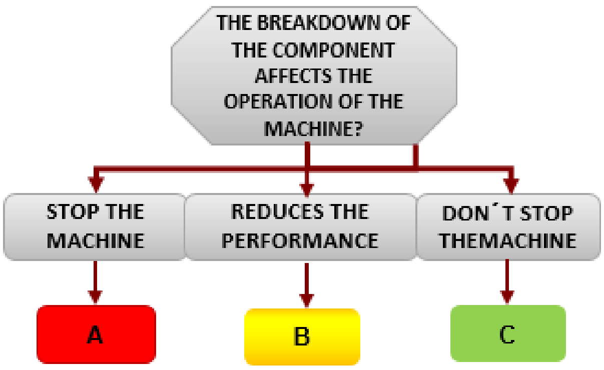
Figure 3.3 – *Tags management*

After each tag is analysed and we try to solve the problem with the building of autonomous maintenance card, for example from the tag which identifies a problem of dirt and damage of the bellows is building the following card (figure 3.4):

Figure 3.4 –*AM Card*

In the first step,another important action is to classify the component in different classes obtaining the following results (figure 3.5):

ABC CRITERIA



Class	#
A	295
B	180
C	28
TOT.	503

Figure 3.5 –*Components classification*

Thanks to the application of the step 1 we reach the following results (figure 3.6):

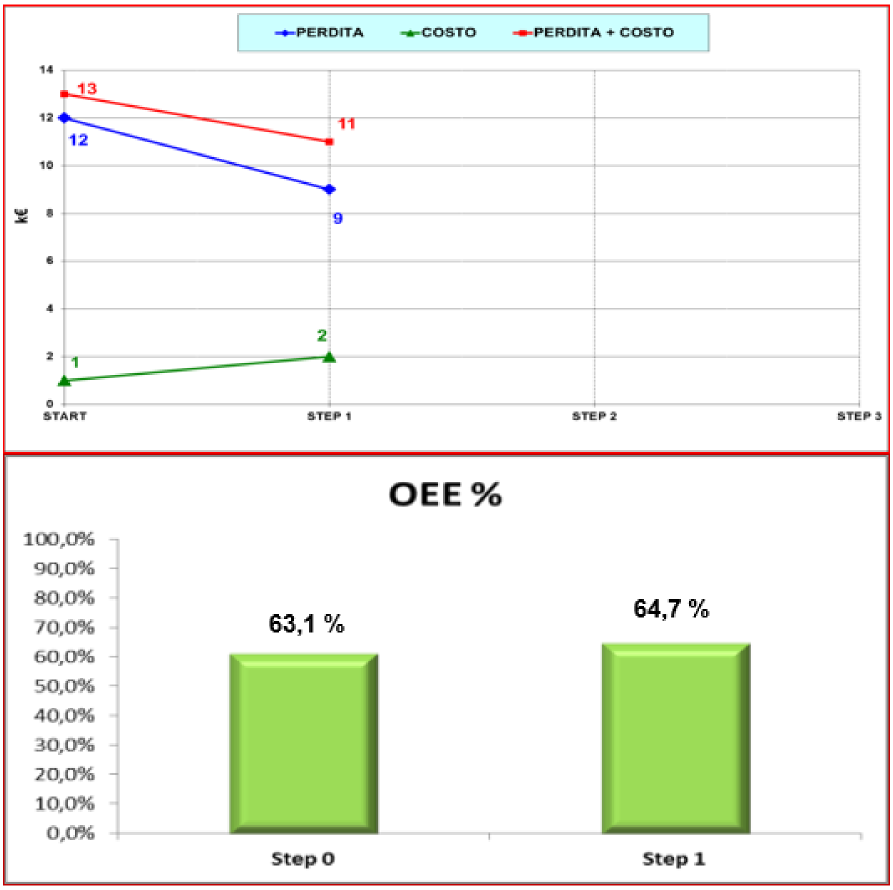


Figure 3.6 –*Step 1 results*

As is shown in the figure 3.6 we obtain an increase of OEE from 63.1% to 64.7% and a reduction of the breakdown losses from 12k to 9k against an increase of maintenance costs from 1k to 2k.

3.1.2 Step 2: breakdown analysis

In the step 2 we monitoring the TBF (time between failure) for each component, we analyse the breakdown with EWO obtaining a stratification by root cause. In the Prawema case we obtain these breakdowns (figure 3.7):

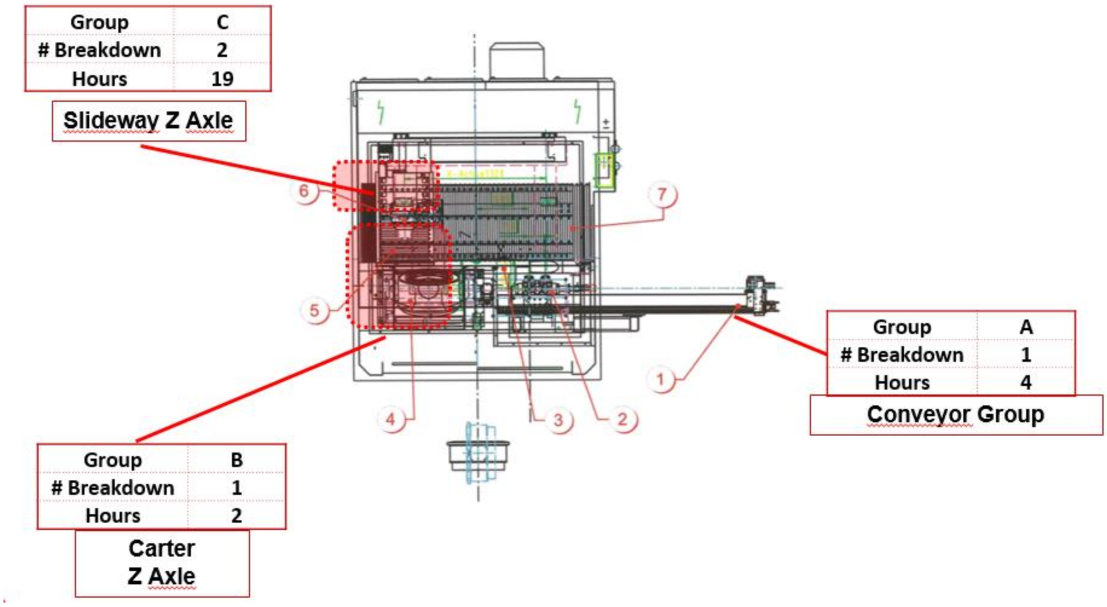


Figure 3.7 – *Breakdown analysis*

With the stratification by root-cause we obtain the following results (table 3.1):

Item	PM	FI	AM	EEM	PD	Total
N° Breakdown	1	2	1	0	0	4
Time [h]	4	19	3	0	0	26
Time Weight %	15,5%	73%	11,5%	0%	0%	-

Table 3.1 – *Stratification by root-cause*

Thanks to the application of the step 2 we obtain an increase of OEE to 65.6% and the reduction of losses to 3k. We obtain also an increase of maintenance costs to 5k (figure 3.8).

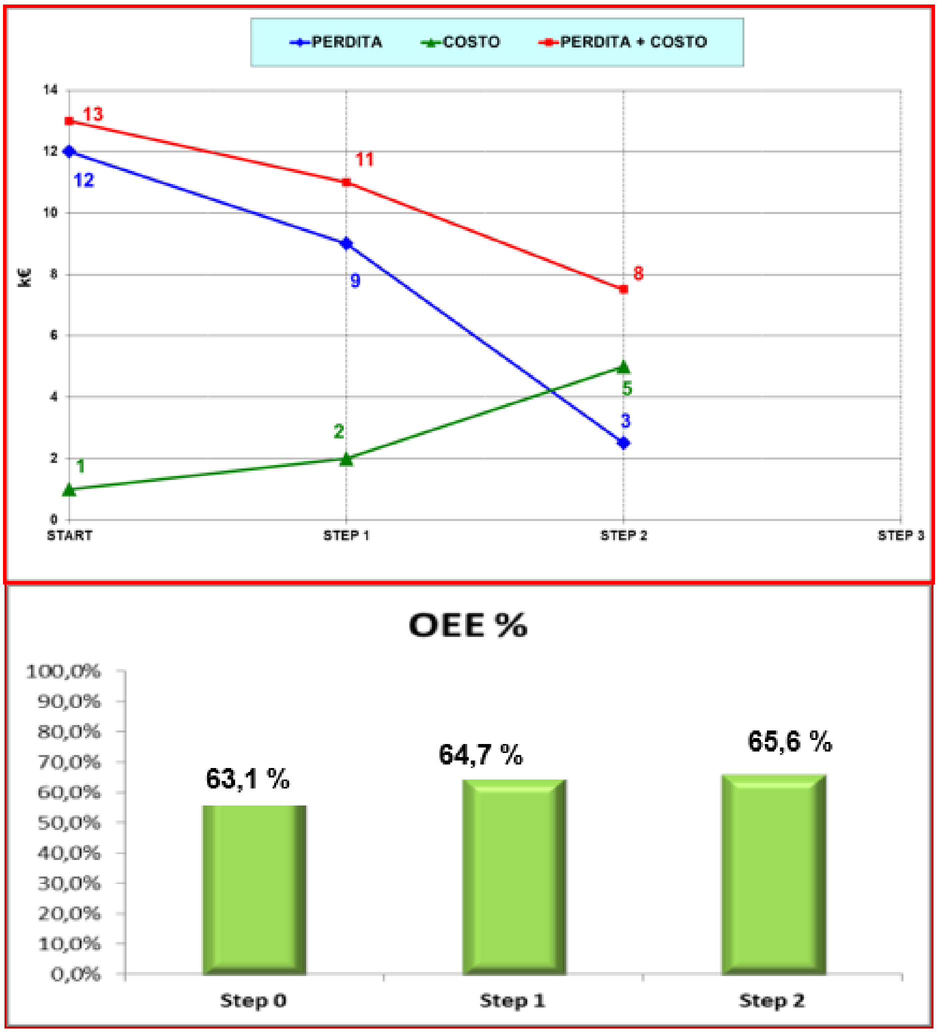


Figure 3.8 – *Step 2 results*

3.1.3 Step 3: Maintenance standards

In this step we implemented maintenance standards by technical specialists using the following sources:

- Machine supplier book
- Breakdown analysis
- Tags and Suggestions
- Component life cycle

From the EWO analysis is possible to building and standardize the Machine Ledger which determine a complete planned and scheduling maintenance for each component obtaining the elimination of breakdown losses due to lack of maintenance.

Thanks to step 3 we reach the following situation (figure 3.9):

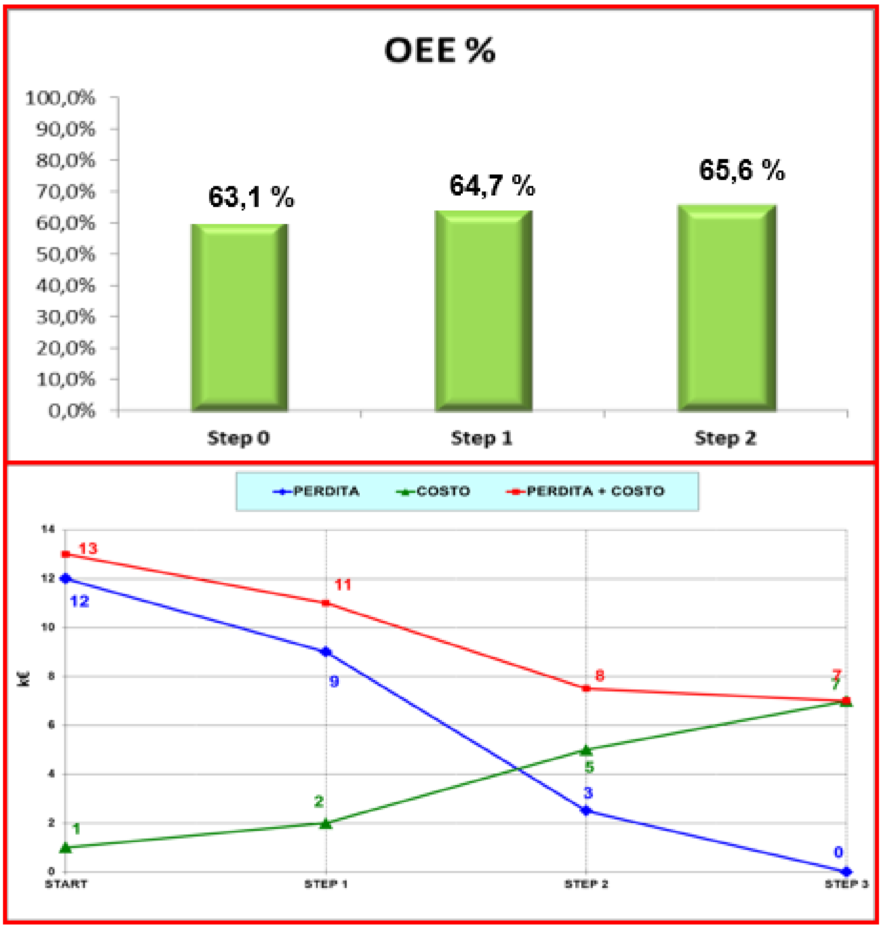


Figure 3.9– *Step 3 results*

As is shown in figure 3.9 we reach the elimination of losses with an increase of maintenance costs to 5 k. The application of the first three steps on the Prawema machine determine an increase of maintenance of 6 k (cost) in the face of a reduction of breakdown losses of 12 k with a global B/C=2 (figure 3.10).

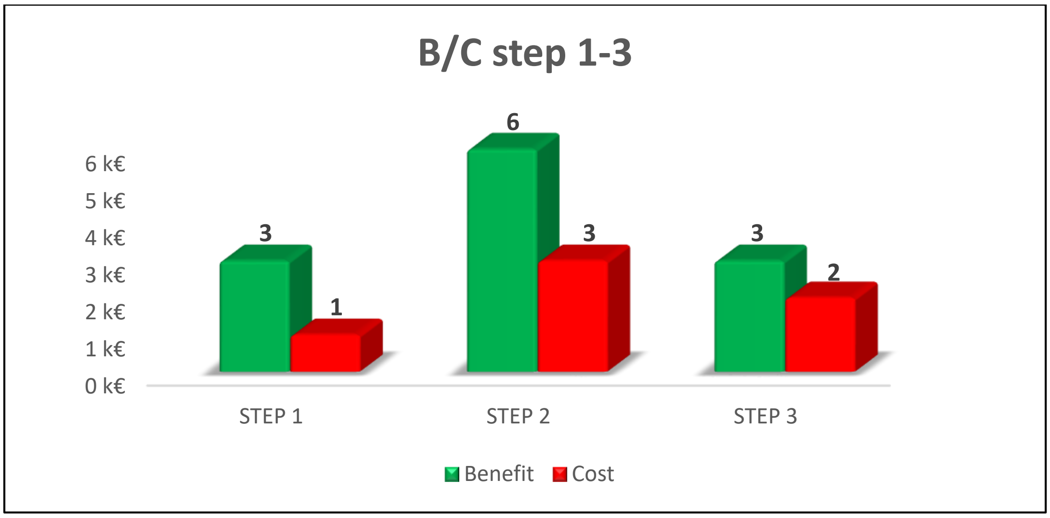


Figure 3.10– *Step 3 results*

3.2 Step 4

In this step, we attack the cost of maintenance to reduce the over-maintenance percentage. The cost of maintenance is evaluated in the following way:

$$COST_M = COST_{SP} \cdot N_R + COST_{LB} \cdot H \cdot N_R$$

Where:

- $COST_{SP}$: cost of spare part (€/piece)
- $COST_{LB}$: cost of labour (€/hour)
- N_R: number of replacement
- H: hours of intervention

The aim of step 4 is to reduce the parameter N_R, with the increase of hardness or with the reduction of the stress and to reduce the parameter H with the reduction of mean time to replace.

3.2.1 Castor 3-The mean time to replace reduction

In this case, we have analysed the Pareto diagram of the maintenance costs of castor 3 (figure 3.11) and we have attacked the highest value of maintenance costs for labour, which is the replacement of electrical motor of vertical conveyor. In the initial condition we have an elastic joint (figure 3.12).

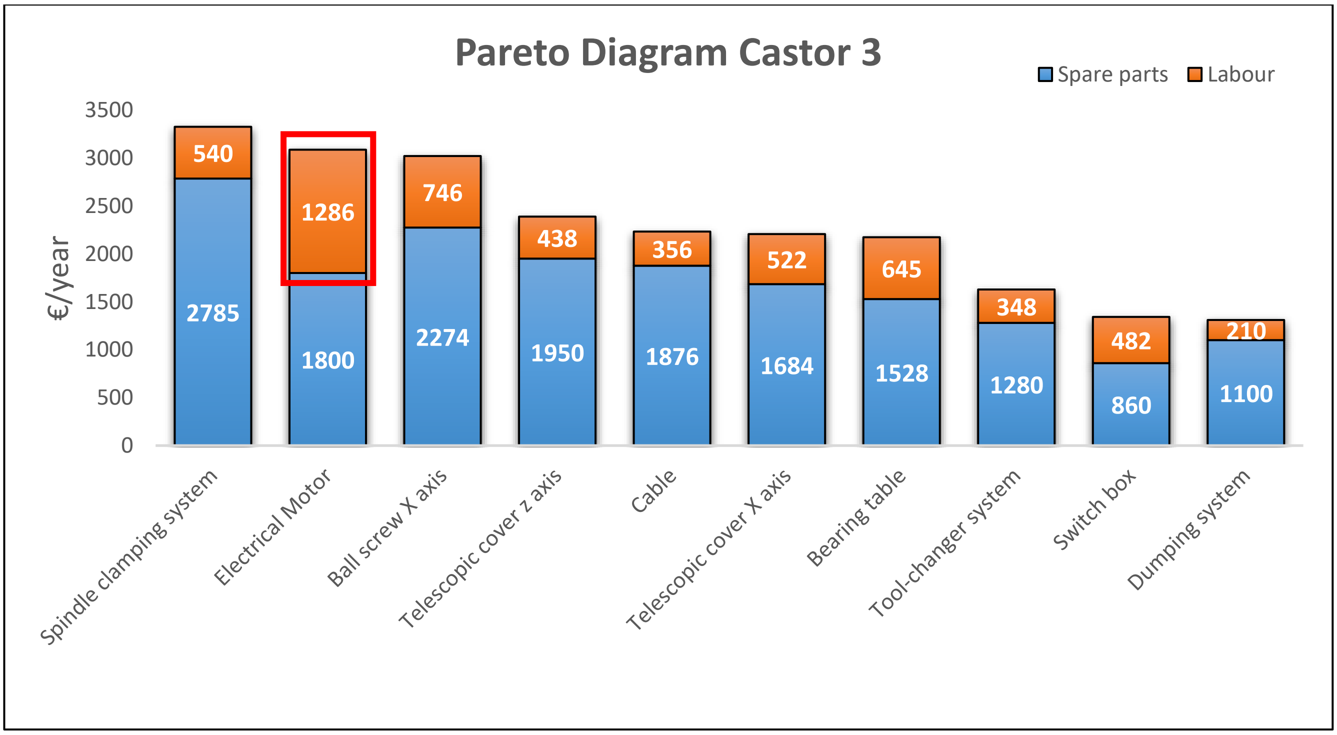


Figure 3.11 – *Pareto diagram*

In the initial condition we have an elastic joint (figure 3.12) linked with the electrical motor.

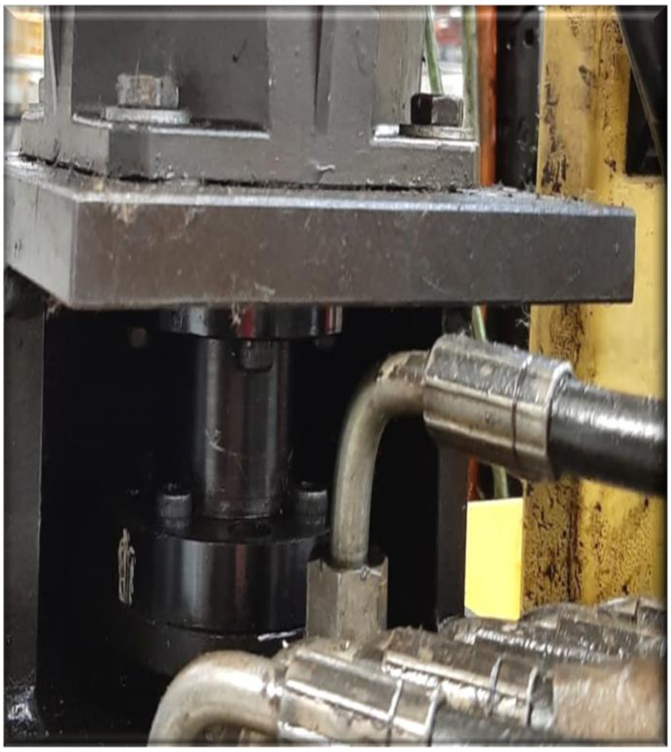


Figure 3.12 – *Elastic joint*

With this configuration the maintenance activities are:

- Motor disassembling and removal
- Screws disassembling (8 screws = 4 + 4)

The stratification of maintenance activities for this operation is shown in the following figure:

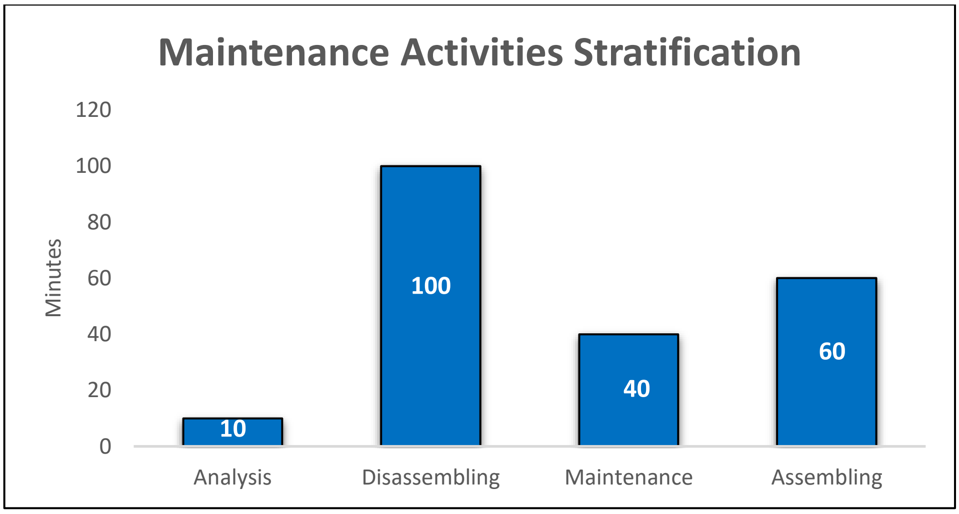


Figure 3.13 – *Maintenance activities stratification*

From the stratification is evident that the disassembling and the assembling phase are the most expansive. For this reason we have replaced the elastic joint with a Rotex joint (figure 3.14)

Figure 3.14 – *Rotex joint*

The new configuration allows to carry out the activity without the disassembling of the motor, moreover there are only four screws. We obtain the following results:

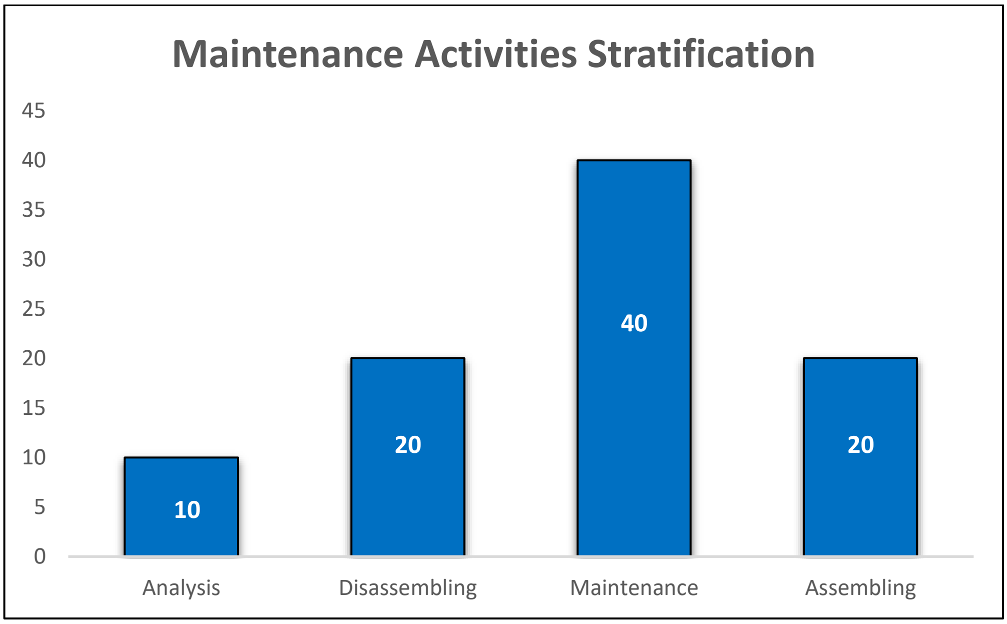


Figure 3.15 – *Maintenance activities stratification*

With this change the maintenance activities move from 210 minutes to 90 minutes obtaining an improvement with B/C=6.9. We obtained a decrease of maintenance costs for the labour as is shown in the figure 3.16.

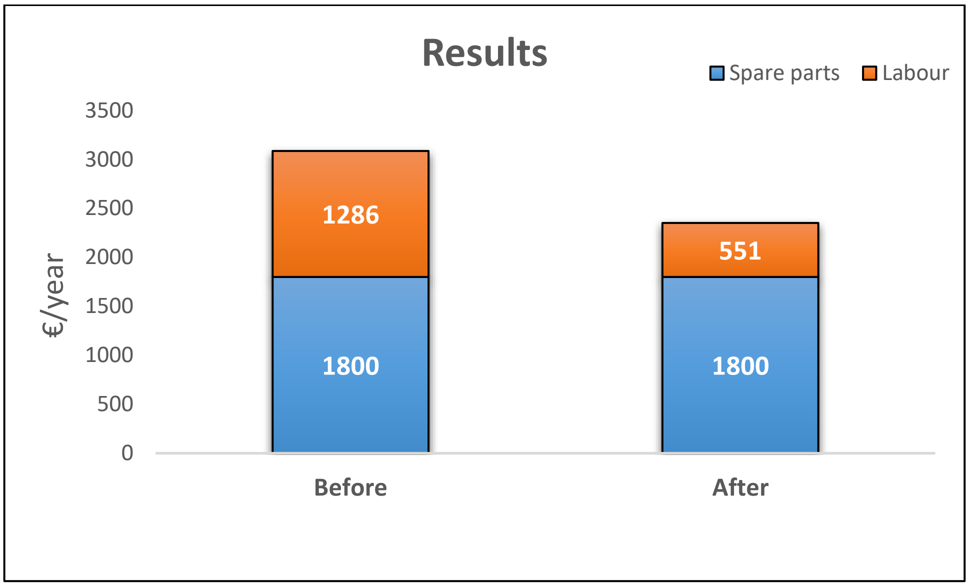


Figure 3.16 – *Results*

3.2.2 Fritz Werner-The stress reduction

The Fritz Werner machine is a machining centre of UTE 7.03. From the Pareto diagram (figure 3.17) is evident that the highest maintenance cost is the brake system of the table.

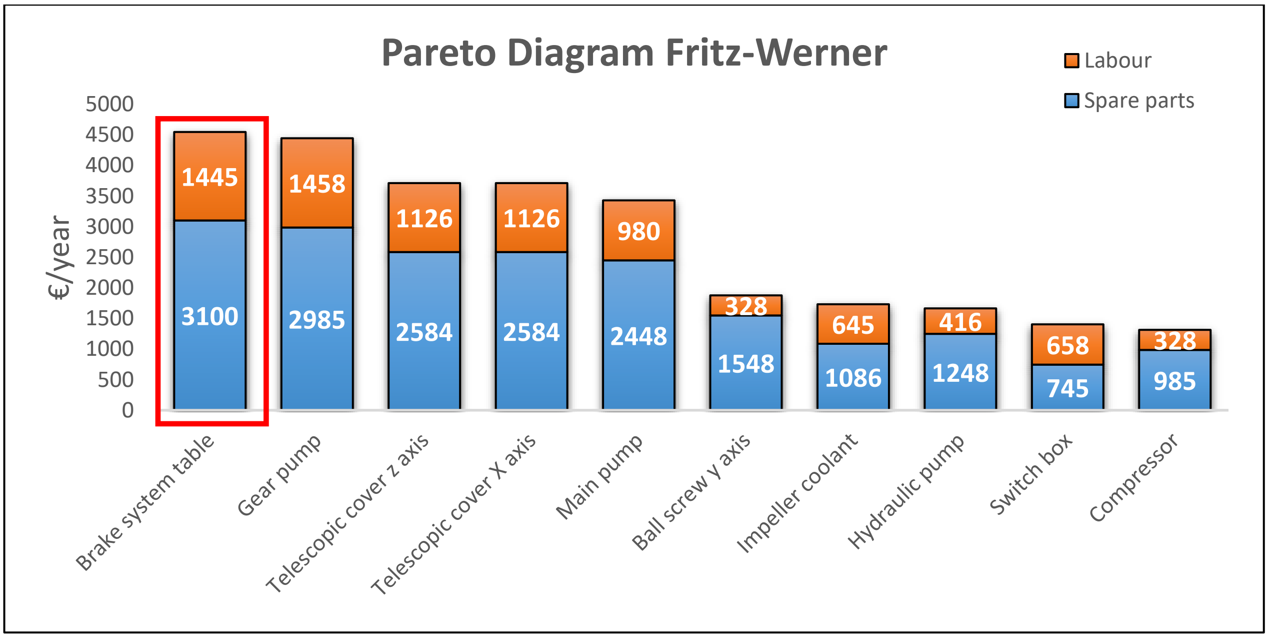


Figure 3.17 – *Pareto diagram Fritz Werner*

In this case, the aim is to increase the life of the component with the reduction of the stress over the component in order to decrease the number of replacement N_R.

The brake system of the rotary table of the Fritz-Werner is a hydraulic and circumferential brake. Thanks to the effect of hydraulic fluid, the brake system adheres to the table blocking its motion. Initially, the brake system worked with a fluid at line pressure and its replacement was one time for a year.

To increase the average life of the brake system we have reduced the stress by introducing of inserted pressure reducer valve. With the new configuration, the replacement frequencies move from one time for year to one time for three a year.

We have reduced the maintenance cost by a third (figure 3.18) with a B/C=3,2.

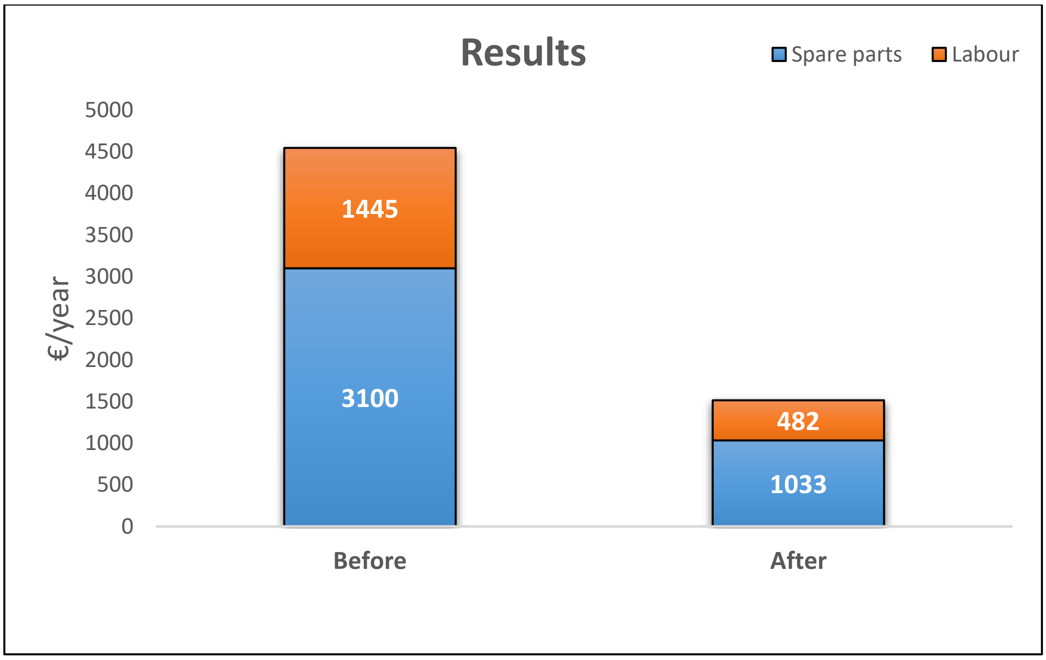


Figure 3.18 – *Results*

3.2.3 Weisser- Increase hardness

This example aim always to reduce the parameter N_R but in this case not with a reduction of the stress but with an increase of the hardness of the component.

The study always starts from the Pareto diagram (figure 3.19) where is identified the highest maintenance cost, which consists of the telescopic cover of Z-axis.

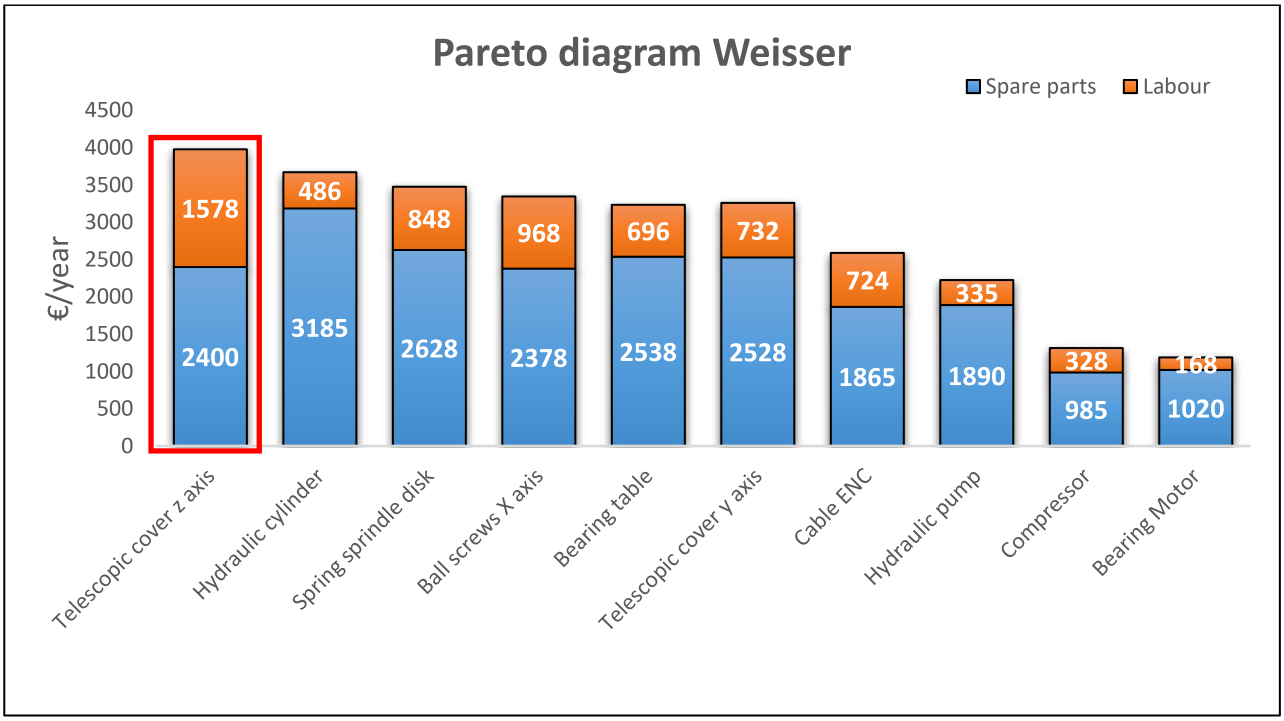


Figure 3.19 – *Pareto diagram Fritz Werner*

The telescopic cover of Z-axis is featured by a simple configuration without a protection of the scraper and the frequencies of replacement is three time for a year. To increase the average life of the telescopic shield we have reinforced using a telescopic shield with a reinforced gasket, which provides protection to the scraper. The old and new configuration are shown in the following figure (figure 3.20)

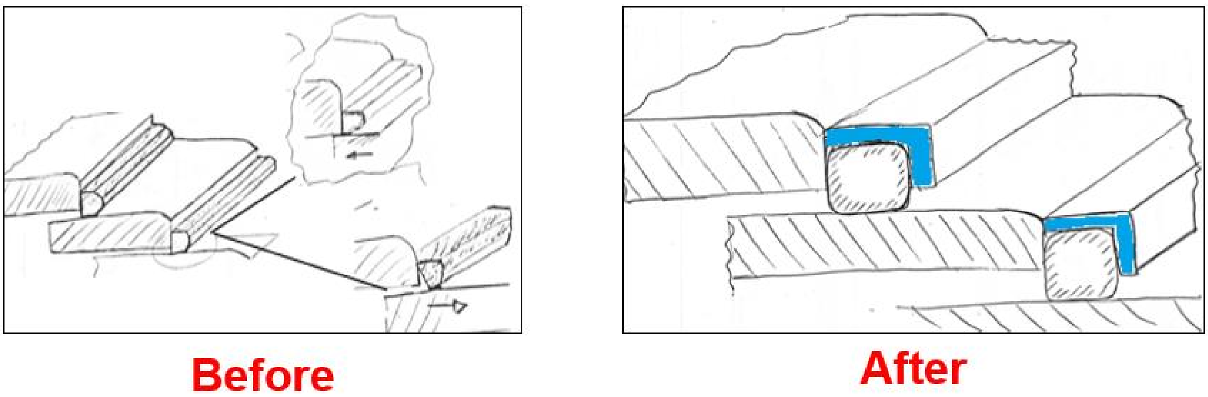


Figure 3.20 – *Old vs new configuration*

We obtained a new frequencies of replacement with two times a year, with a reduction of maintenance costs as is shown in the figure 3.21 with a B/C=2.1.

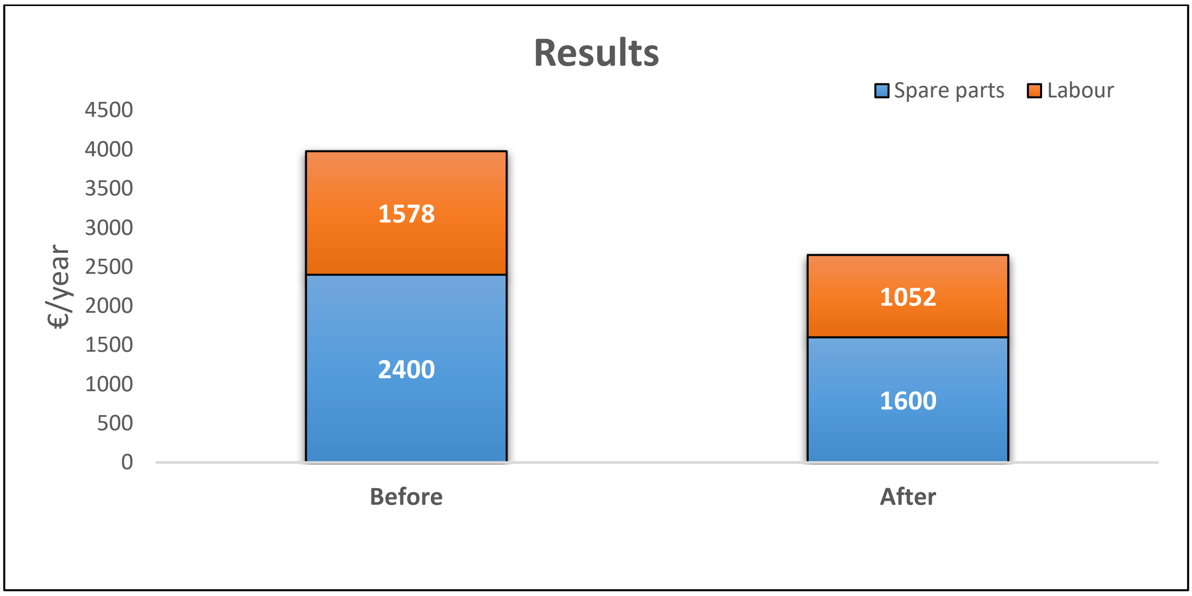


Figure 3.21 – *Results*

3.3 Step 5

In this step, we have to build a periodic maintenance system in order to reduce the replacement frequencies. Is reported below the example of the application of the step 5 to the EMAG Mozzetti machine.

3.3.1 Emag Mozzetti- Creation of periodic maintenance system

We start from the analysis of the Pareto diagram of the EMAG Mozzetti machine, where are reported the maintenance costs with the stratification in labour and spare parts cost.

From the Pareto diagram (figure 3.22) is evident that the biggest cost of maintenance is the impeller coolant pump (figure 3.23):

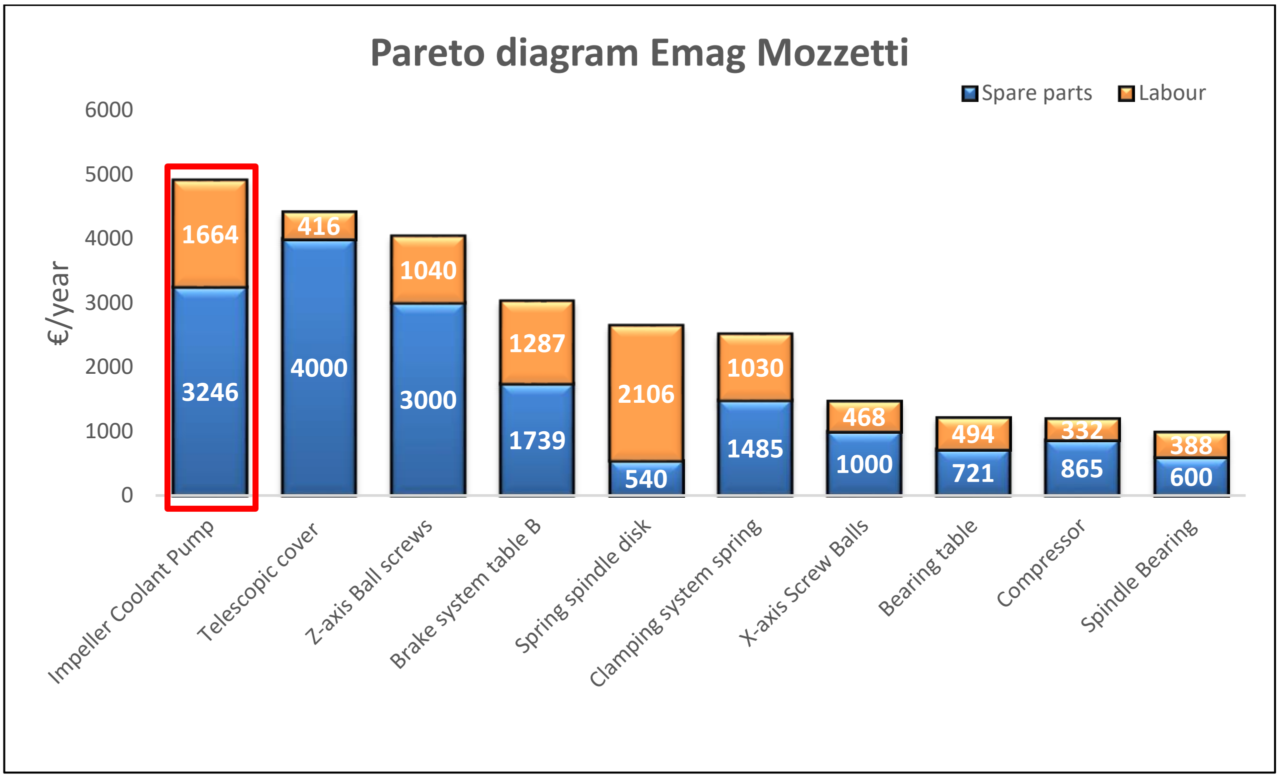


Figure 3.22 – *Pareto EMAG Mozzetti*

Figure 3.23 – *Pump*

The maintenance program, building thanks to the help of the supplier, provides for replacing the impeller coolant of the pump every six months. In according to the rules of the step 5 we identify the dimension of the component representative of its deterioration, which is, in this case, the external diameter of the impeller.

The operative flow of the pump is between 150 and 180 l/min, for this reason, we identify three characteristic flows in relation to the corresponding characteristics diameter:

1. Q_{MAX}=180 l/min with d_{NOM}=100 mm
2. Q_{SAF}=160 l/min with d_{SAF}=94mm (safety limit)
3. Q_{FAI}=150l/min with d_{FAI}=90mm (failure limit)

After the first replacement, we measured the diameter of the impeller obtaining d=98.16 mm. For this reason, we decide to replace the new impeller after 12 months measuring again the diameter of the impeller and obtaining d=95.04 mm.

We have obtained a positive measurements that means the component was not fully used and so the replacement frequencies can be reduced (figure 3.24)

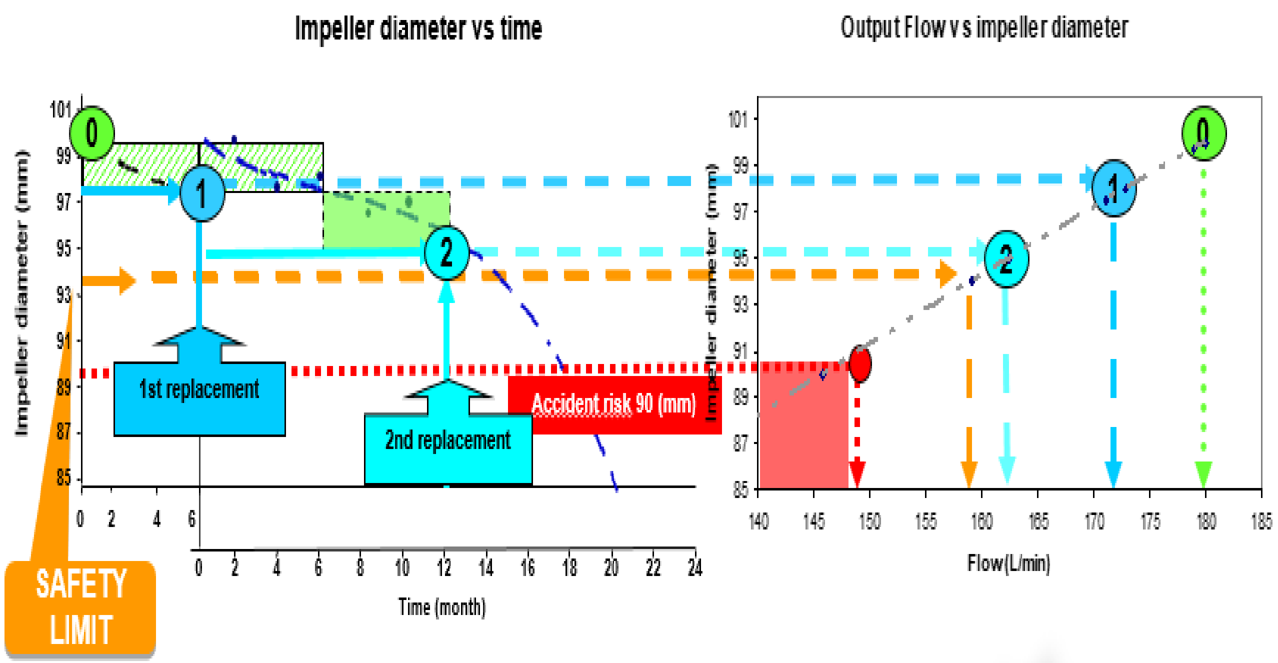


Figure 3.24 – *Revise frequencies*

We changed the frequencies of replacement from 6 months to 12 months achieving:

- The halving of maintenance costs with a result R=2400 € (figure 3.25)
- The cost of maintenance activities is C=550 €
- The benefit B=R-C= 1850 €
- B/C=3,4

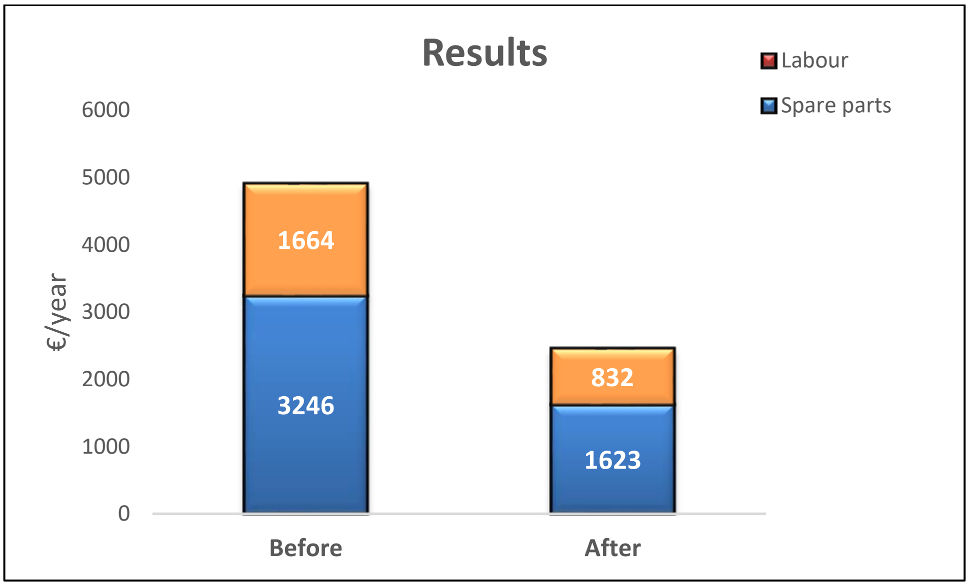


Figure 3.25 – *Results*

3.4 Step 6

In the step 6 we move from TBM approach to CMB approach. In TBM, we are sacrificing the useful life of the component, changing component much before its estimated life to avoid breakdown while in CBM, we try to maximize usage of components life. This is achieved by monitoring critical parameters of component, which speaks about its condition.

Are reported below two examples of step 6:

1. Famar-spindle clamping
2. Grob X-Way- Smart Observer Application

3.4.1 Spindle clamping- Famar Machine

The famar machine is a horizontal lathe of UTE 7.02. According to the specification from the supplier, every 12 months we have to replace the spindle's clamping group (figure 3.26).

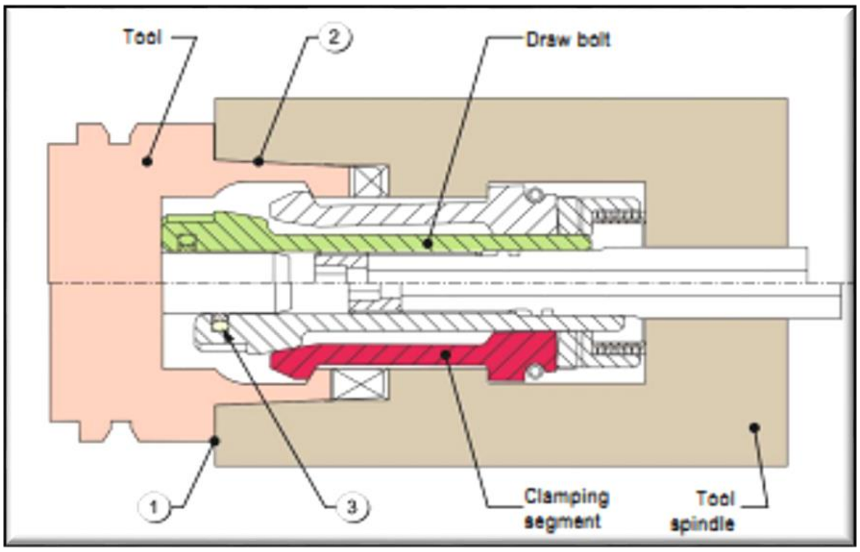


Figure 3.26 – *Spindle clamping group*

Always by the manufacturer specifications, we know that the clamping force should be between 45 kN and 30 kN, for this reason we identify the fields for the clamping force which are shown in the following figure (figure 3.27):

NOMINAL FORCE	**35KN<F<45 kN**
SAFETY	**30KN<F<35 kN**
FAILURE RISK	**F<30 kN**

Figure 3.27 – *Force fields*

For this reason, we have decided to monitor constantly the clamping force of the spindle, in order to build the characteristic curve of the parameter which determine the deterioration of the component. The construction of the curve allows to predict the behaviour of the component and so determine the passage from time based maintenance TBM to condition based maintenance CBM. The safety zone is evaluated in relationship with the lead-time of the component.

Every month we have measured the clamping force inserting a force transducer in the spindle of the machine as is shown in the following figure (3.28):

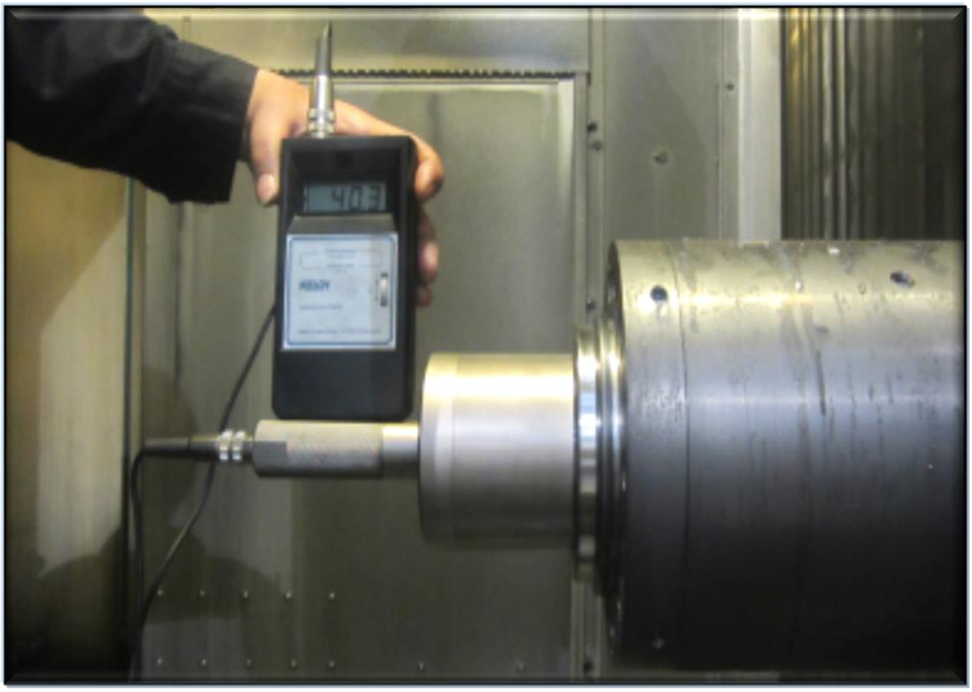


Figure 3.28 – *The clamping force evaluation*

The results of measurements are showed in the table below:

Month	10	11	12	13	14	15	16	17	18	19
Mis1	41,5	40,3	39,6	38,8	38,2	37,5	36,8	36,2	35,3	35
MIs2	41,3	40,4	39,5	39,1	38,4	37,9	37	36,4	35,7	34,9
Mis3	41,5	40,8	40,2	39,8	38,6	38,2	37,5	37	35,4	34,7
Mis4	41,7	41,2	40,4	39,6	38,5	37,9	37,1	36,3	35,1	34,3

Table 3.1 – *Measurements*

With the values of table 3.1 is possible to building the following curves (figure 3.29)

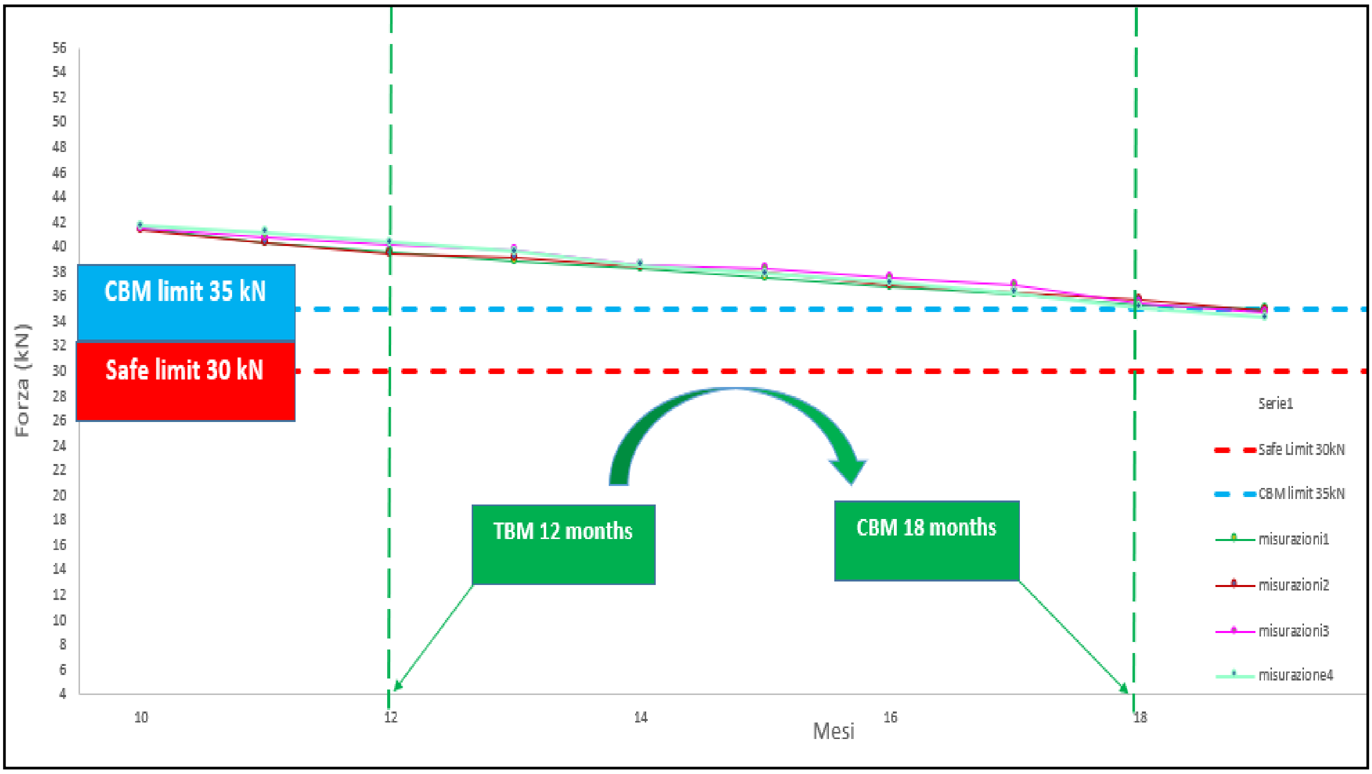


Table 3.29 – *Trend management*

With the continuous monitoring of the clamping force we obtaining a revision of frequencies replacement from 12 months to 18 months (figure 3.30) with a reduction by a third the cost of maintenance with a B/C=1,4.

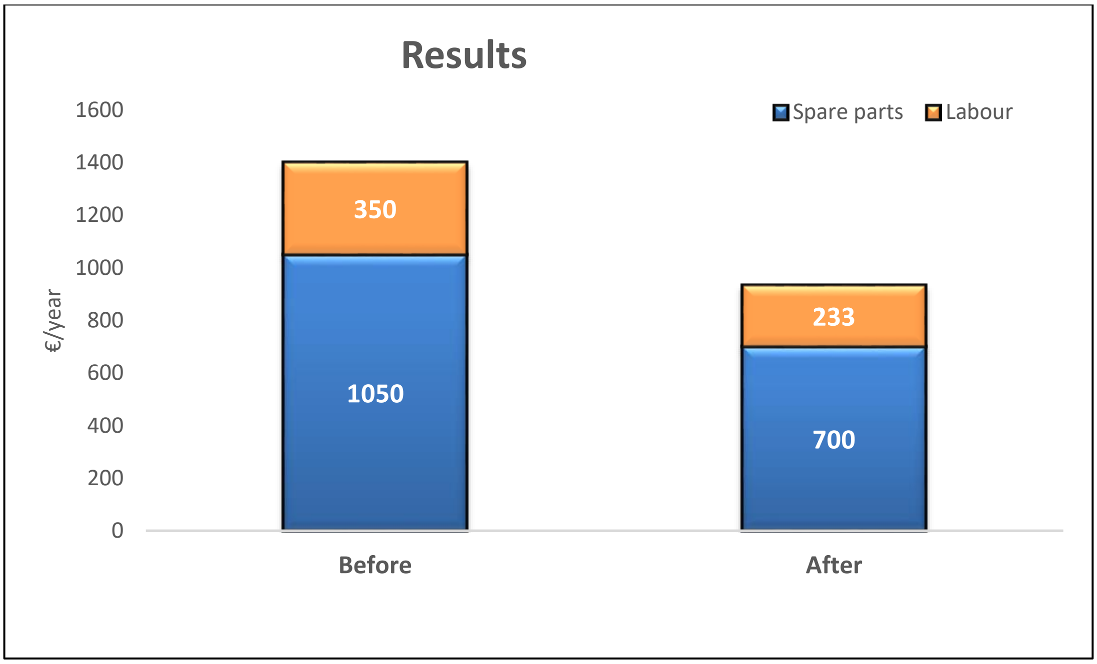


Table 3.30– *Results*

3.4.2 Smart observer application- Grob X-way

The Grob X-way is a machining centre of UTE 7.05, which is part of the X-way line. The X-way line is composed by two vertical lathe of Famar and two machining centre of Grob. The line is monitoring constantly thanks to the installation of the Smart Observer.

The smart observer is a software of IFM electronic, a German company that produce sensors and controllers. With this software and thanks to the installation of different sensors on the machine is possible to monitoring in real time the condition of the machine.

The installation of Smart Observer ensures the following benefit:

- Continuous diagnostic with the development of a predictive maintenance system
- Early detection thanks to the alarm system
- Highest efficiency
- Simple integration of the sensors in the analysis system

Thanks to this technology is possible to monitoring each machine of the line:

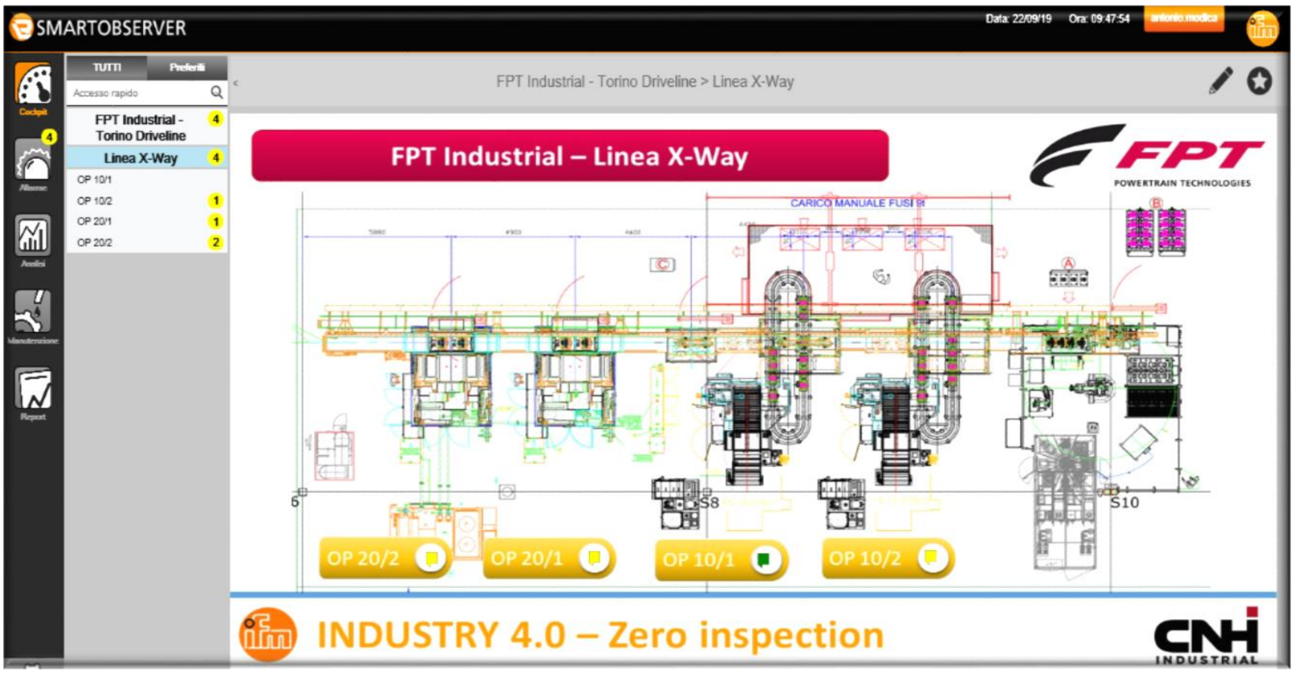


Figure 3.31 – *X-Way line on Smart Observer*

In this line, thanks to the installation of the sensors, we are able to monitor different aspects:

- Spindle vibration
- Pump vibration
- Energy consumption
- Oil (temperature, humidity and quantity)

- Air (temperature and flow)
- Coolant (temperature and flow)
- Electrical cabinet (temperature)

The effectiveness of this control system depends from an optimal choice of the limit for the alarms, which determine three zones:

- Nominal zone: the colour of the alarm is green
- Safety zone: the colour of the alarm is yellow
- Danger zone: the colour of the alarm is red

Is possible to monitoring the machine condition on the machine thanks to the installation of ifm monitor (figure 3.32) or directly on your personal computer. Moreover is possible to receive a message on your mobile phone if the alarm limits are exceeded.

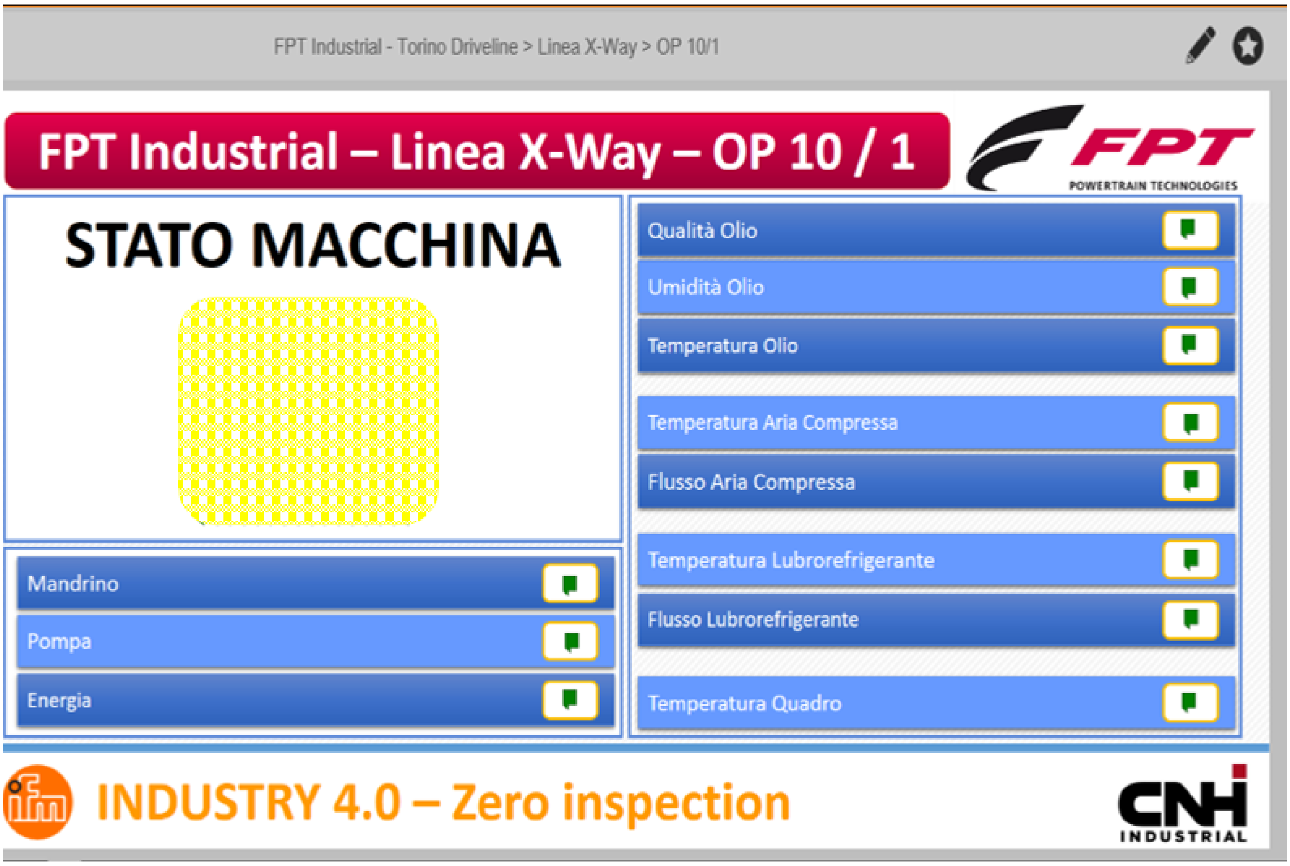


Figure 3.32 – *Alarm system*

An important application is the utilization of the sensor LDH100 which measure the quantity of water contained in the oil with a percentage from 0% to 100% (figure 3.33). If the oil becomes turbid, free water is already present. Depending on the type of oil, the absorption capacity of the water can vary considerably.

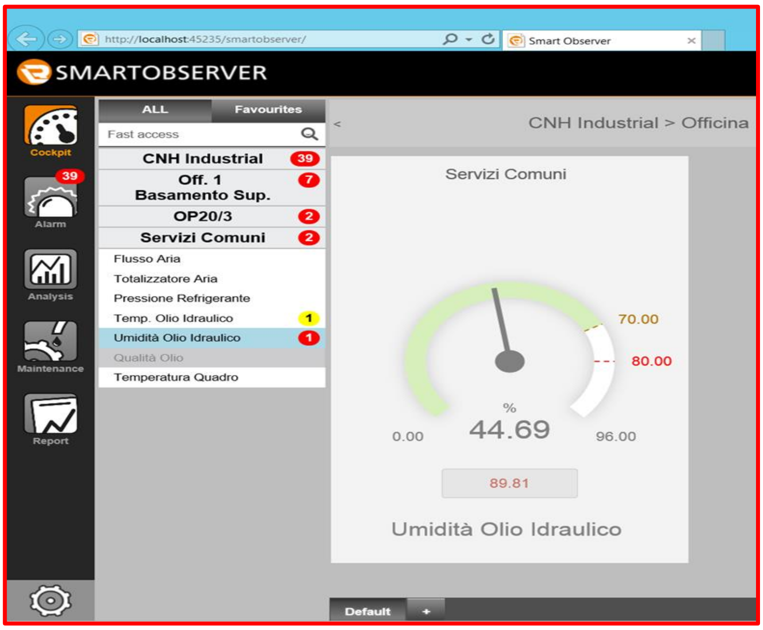


Figure 3.33 – *Humidity oil alarm*

It is also possible to monitor the oil condition real time (figure 3.34):

Figure 3.34 – *Real time*

When the trend reach the red line the saturation affect the effectiveness of the oil and for this reason it can be replaced. With the monitoring in real time, we obtained the prevention of damage due to water infiltration and the oil life extension.

With this system, we move from the frequencies of oil replacement of 4000 h (a year) to 5200 h (a year and 4 months).

3.5 The step 7

The step 7 consist of the management of maintenance costs. The development of this step has not yet been performed on some machine but we are working to implement the financial risk deployment.

The Financial Risk Deployment is used to support and drive decisions concerns the machine obsolescence and potential losses. The Risk Assessment is used to implement measures of effectiveness, providing the guidelines in terms of investments priority aimed to the risk elimination. The risk index is affected by several factors and allows to define the critical issues and priorities to be attacked.

The financial risk deployment is organized in seven steps (figure 3.35):

1. Risk analysis: identify risk areas and allocate risk into process
2. Identify risk quantitatively and quantify risks in terms of reverity
3. Define probability in time for the risk
4. Risk financial impact
5. Risk treatment
6. Cost-risk reduction
7. Post project risk assessment

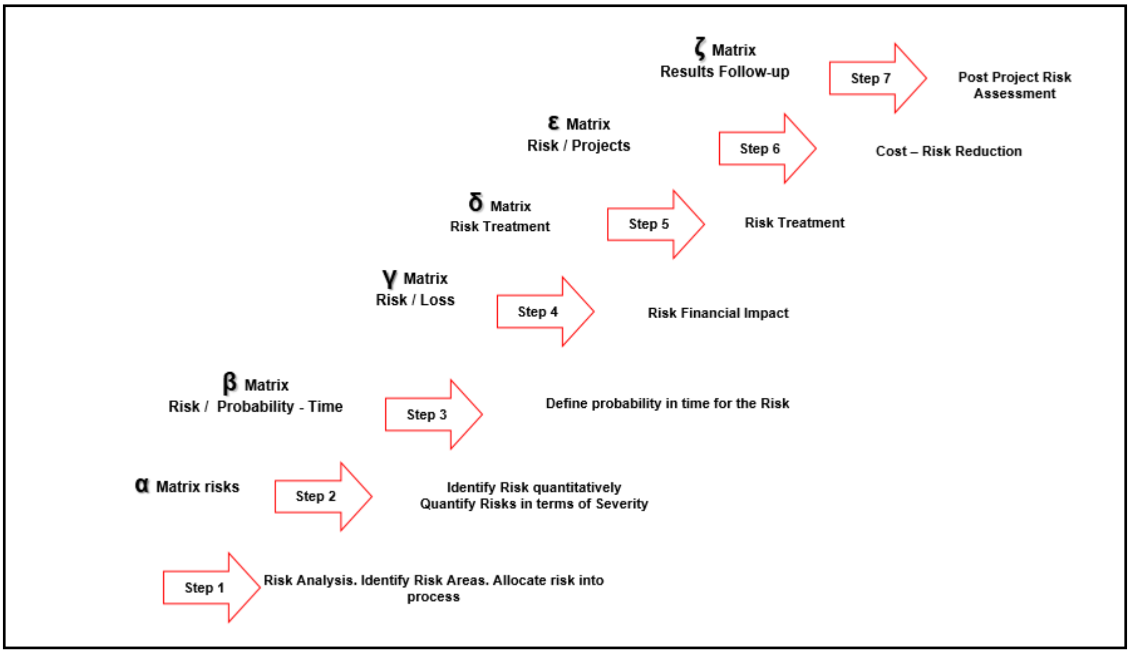


Figure 3.35 – *Financial Risk*

3.6 The overall results

The proper application of the Professional Maintenance pillar should ensure the elimination of the breakdowns of the machine due to lack of maintenance with a continuous reduction of maintenance costs.

Analysing the application of the first three steps is evident that we have eliminated the breakdowns of the machining increasing the reliability and the efficiency of each component with the creation of a planned and scheduled maintenance program. This involves an increase in the maintenance costs so the next steps aim to the reduction of these.

In step 4 we have attacked the maintenance costs, which depend from the cost of the spare part and from the cost of labour. We have obtained a reduction of the frequencies of replacement with the decrease of the stress on the component or with the increase of the hardness of the component. We have also reduced the hours of the maintenance intervention with a consequently decrease of maintenance expansive.

In step 5 instead, we have built a periodic maintenance system and with the determination and the analysis of the parameter that represents the deterioration of the components, we have changed the frequencies of replacement with a reduction of the maintenance costs.

In the step 6, we move from the time based maintenance approach (TBM) to condition based maintenance approach (CBM) with the building of the characteristic curve of the parameter, which determines the component deterioration. Thanks to the curve, we are able to predict the condition of the component and we have maximized the usage of component life.

Overall, therefore, we have eliminated the breakdowns with the reduction of the costs and with the step 7 we will try to build a management system for the maintenance costs.

4 The future prospective and the criticality

In this chapter is analysed the future prospective in the Driveline Plant with particular regard to future maintenance activities. Finally will be discussed some criticalities personally identified about the application of the World Class Manufacturing method and the Professional Maintenance pillar.

The future of manufacturing in fpt industrial is based on the adoption of the ideas and guidelines of industry 4.0

4.1 The Industry 4.0

The industry 4.0 is a process that flows from the fourth industrial revolution that allows to reach a high level of automation of the manufacturing system. CNH Industrial has developed a political of implementation of the industrial 4.0 in according with the investment plan of the Italian government.

In the Driveline Plant the application of the industry 4.0 consist of:

- Predictive Maintenance
- Cobots
- Augmented reality
- Virtual reality simulator
- Motion capture
- Exoskeleton
- 3D Printing
- Adaptive AGVs
- Smart communication
- RFID

Thanks to the installation of the smart observer, a software from IFM we are able to develop a system of predictive maintenance. This aspect has already been treated in the step 6. In this moment the smart observer in installed only on the X-Way lines, the target is to install it on the other important line in order to monitor in real time the condition of the most important machine of the plant.

Another important aspect of the industry 4.0 is the installation of the Cobots, which are collaborative robots able to work in contact with man recognizing his presence in order to reduce the space occupation and the cycle time. For this reason was installed in UTE 7.03 the Comau Aura (figure 4.1). This robot allows to work with the human side by side, completing themselves with unique abilities with the introduction of the following benefits:

- Optimized working process
- Fully collaborative robotic system
- Floor place reduction
- Easy re-programming

- Easy integration with other components

Figure 4.1-*The Comau Aura*

The features of the Comau Aura are:

- High payload (170 kg the highest for Cobot)
- 6 safety layers (laser scanner, FOAM skin, proximity sensor, contact sensor, force sensor, manual guidance)
- Collisions avoid system
- High speed collaborative mode
- Collaborative/ non-collaborative mode switch
- Collaborative end effector
- Possibility to mount the robot upside down

Another important activity is the installation of 3D printing in order to introduce the concept of additive manufacturing. The 3D printing is used for reproducing component and to develop faster prototypes with the reduction of the manufacturing time and of the costs because the prototypes production, before the installation of the printing, was entrusted to an external supplier.

The 3D printing was very useful during the pandemic for the Covid-19, in fact, several devices (figure 4.2) have been produced to avoid contacts in the company in line with the provisions imposed by ministerial decrees.

Figure 4.2- *3D printing devices*

Always in view 4.0 is the purely maintenance project of the installation of e-PMM software, in order to:

1. Computerize maintenance activities management and workload
2. Increase accuracy and consistency of data collection

E-PMM is a software realized to manage the maintenance activities with various maintenance policy like MC (maintenance cycle), MP (planned maintenance) and PI (first aid) linked with SAP maintenance. It is born to need of maintenance team to manage in simplified methods the maintenance crew and the activities for every single shift.

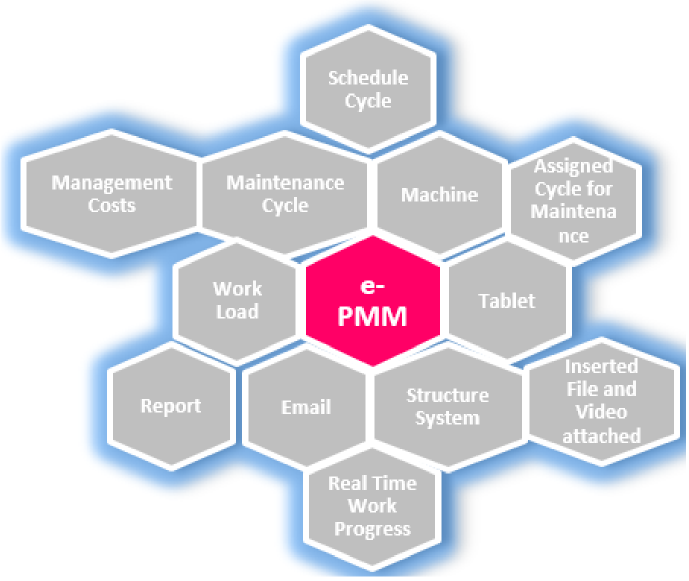


Figure 4.3- *e-PMM*

In parallel with the e-PMM, an automatic system for compiling EWO is also being developed from the maintenance team. The EWO (emergency work orders) is the document that is compiled, when the breakdown occurs, in order to determine the root cause of the breakdown.

The procedure for the EWO compiling provides for:

1. Manual compiling by the maintainer
2. Upgrade on the database by the maintenance specialist
3. Manual activity of stratification of the root cause
4. Manual activity of identification of the UTE, the machine and the Operative Unit

This program is complex, required a lot of time and manpower and determine the following situations:

- High EWO build time
- EWO not complete dispersion Data
- High storage and search time
- Chart update - Not available
- Root cause stratification - Not available
- Stratification by Pillar - Not available

With the new system, the compiling is computerized and for this reason the EWO automatically upgrade on the server.

With the new configuration, we have the following advantages:

- Reduce EWO build time + EWO quality
- Get full EWO compilation
- Historian EWO
- Search options (Unit/UTE/Machine/Time period)
- Stratification by root cause/ by pillar
- Real-time graph update
- Email to Pillar Team

4.2 World Class Manufacturing and Professional Maintenance criticality

Overall, the application of the WCM method allows the achievements of excellent results, in fact, after the development of the seven steps program for each pillar, we reach the ideal condition of zero breakdowns, zero defects, zero stock and zero waste with a total respect of the environment, the elimination of accident on the workplace and with an important attention towards costs.

Therefore, the application of the WCM is without a doubt an advantage for the company but there may be some critical aspects.

First of all the method was thought and built for the automotive sector and for this reason is more difficult to apply the methodology in other fields. For example, in the food industry, there are different prerogatives compared to automotive and the product contamination is more dangerous.

Another important aspect to consider is the standardization, which represents one of the main aspects of the WCM, in fact, the methodology is the same all over the world. This aspect is significant advantages for the management because the situation of each plant is evaluated with a system of KPI (key performance indicators) but in the other hand, it could be limiting in the analysis of the manufacturing activities. For example, the maintenance conditions of a vehicle plant are different from the conditions of a machining plant. In the machining plant, there are many different machines with different technologies, the layout is usually with stand-alone machine or with small lines. In the vehicle plant, instead, there are long lines with the installation of similar machine like robot (taping), screwdrivers and AGV. For this reason in the vehicle plant is easier to understand the root cause of the breakdown and to apply an improvement on the other machines. On the other hand, in the vehicle plant the time of machine stop is much more harmful because the final product is a vehicle and not a piece or component.

At last, another critically of the WCM system is, in my opinion, the state of agitation due to the Audit. During the Audit, everyone has his targets and his activities. For a correct development of the WCM is important the collaboration of each company areas and overall is important the collaboration of all Pillars. When the audit is close and time is short, this collaboration could be less risking to compromise the success of the Audit.

5 Conclusion

Overall, the World Class Manufacturing represents a structured model of company management, which aims to the continuous improvement and to reach the efficiency in all aspect of the manufacturing system.

The continuous improvement is obtained with the decomposition of the manufacturing activities in ten technical pillar and for each pillar is expected a program of improvement divided into seven steps.

One of the technical pillar is the Professional Maintenance (PM), which organize the maintenance activities made by the maintenance team trying to get the zero breakdown losses condition in all areas of the manufacturing plant.

The correct application of the WCM system ensures the reach the expected results and this aspect is evident in the Driveline Plant Torino of FPT Industrial when the manufacturing system is organized according to the guidelines of WCM since 2007. As we have seen, the strategy of PM pillar allowed us to gain the wanted target.

The PM strategy is easy to apply but it required the full involvement of the human resources of the company. It starts, with the reactive phase, trying to solve the main problems determined by the lack of maintenance that is the run of machine breakdown, which cause economic losses because the machine goes down. Thanks to the identification of the root cause of each breakdowns of the machine is possible to building a program of scheduling maintenance with the achievement of the zero breakdown condition.

Therefore, we arrive in the preventive phase, where we have no breakdown but with the highest value of the maintenance costs. We have an unnecessary cost component in order to achieve the goal (over-maintenance) and for his reason, in this phase, we try to reduce the maintenance costs with the extension of the useful life of the components or with the improvement of maintenance activity. With the building of periodical maintenance system, we move from preventive to proactive phase.

In the proactive phase, we are able to monitor in real-time the conditions of the component and for this reason, we use all the useful life of the component, changed it before the breakdown occurs. Moreover, with the building of costs management system we control efficiently the trend of maintenance costs.

Definitively, the World Class Manufacturing is the best way to organize the manufacturing system ensuring the maximum efficiency of the production system with a continuous reduction of the costs resulting in an increase in the added value of your product.

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