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TOTAL PRODUCTIVE MAINTENANCE: A CONTEXTUAL VIEW IN FISCHER ITALIA

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Introduction

Total productive maintenance (TPM) is a manufacturing strategy that has been successfully employed globally for the last three decades. A prerequisite for benefiting from TPM is to measure the performance of TPM activities. Although overall equipment effectiveness (OEE) has widely been used as a performance measure of TPM activities, it is a measure for TPM effectiveness. It is also required to measure the performance of TPM implementation in terms of efficiency. Nevertheless, implementing TPM is not an easy task. Innumerable barriers are encountered in real-life cases during TPM implementation.

This study wants to show that the adoption of TPM improves considerably availability and reliability of machines, trying to achieve, in the long term, a result of zero defects, zero accidents, and zero breakdowns. TPM tools provided by literature will be implemented in an Italian branch of a German firm: Fischerwerke GmbH & Co., which produces fixings and anchors. This study starts with a description of the Lean approach to focus, successively, on Total Productive Maintenance. After a short description of the firm, Fischer Italia placed in Padua, and its current maintenance program, it is described the entire process of implementation of the new approach for two production departments: moulding and automatic packaging. The activities consist of:

- Teaching to employees TPM principles.
- Defining TPM for each of the operative centre.
- Defining OEE target for each operative centre.
- Defining a maintenance program for each operative centre.
- Analysis of errors and countermeasures.
- Creation of a program for predictive maintenance for each operative centre.

The results achieved, analysing OEE and some KPIs, provide an increased understanding of how TPM has affected the effectiveness and the profitability of the firm. However, the real aim of this thesis is the analysis of which of the contextual factors (operative variables within the firm) have an impact on indicators of performance. The work shows which variables impede or facilitate a fast fulfilment of results in a short-term period.

Chapter 1

Lean Approach

1.1. Lean Principles

Lean Production can be defined as a philosophy or a strategy, which depends on a set of practices used to minimize waste in order to improve an enterprise's performance (Womack, J.P., et al., 1990).

The main objective of lean thinking is the maximization of value for buyer and the simultaneously reduction of resources to achieve it. This approach starts by defining value for customers trying to understand what they really want, how they solve a problem or need, and then defining all the operations to achieve that product or service has still desired. Lean philosophy is obtained by the restructuring of the processes according to the five principles of lean (Womack, J.P., Jones, D.T., 1996):

1. Specify Value
2. Identify the value stream
3. Flow
4. Pull
5. Perfection

That releases the best managerial resources to reinvest in new strategic approaches, following a continuous growth.

First of all the lean approach redefines the concept of value, that is not what the company produces but a measure that the customer "gives" to the product or service that meets his needs at a specific time at a specific price. Therefore, the customer becomes the focus of analysis and everything goes around him. The company, starting from the customer value, has to design the right product or service and determine the related target cost based on the amount of resources and effort required to produce it. This cost has to be considered after the complete elimination of *muda* (waste) from the process. Once the target cost is set for a specific product, it becomes the lens for examining every step in the value stream for product development, order taking, and production.

Value stream is about viewing your product delivery system as a continuous flow of processes that add value to what you create. All the actions for the realization of the product can be divided into three categories:

1. those which actually create value as perceived by the customer;
2. those which create no value but are currently required by the product development, order filling, or production systems (Type One *muda*) and so can't be eliminated just yet;
3. those actions which don't create value as perceived by the customer (Type Two *muda*) and so can be eliminated immediately.

Value Stream Mapping (VSM) is a visual representation of the company processes that helps to visualize the station cycle times[1], changeover time[2], inventory at each stage, manpower and information flow across the supply chain. It is an important tool for any enterprise that want to be lean. The key benefit of VSM is its focus on the entire firm stream to find system wastes and to avoid the pitfall of optimizing some local situation at the expense of the overall optimization. Its main strength is that it shows the linkage between the information flow (what to make or do next) and the material flow. VSM is applied grouping products that belongs to the same family. The purpose of product family[3] recognition is to identify which product family would result in the maximum business impact after improvement. Product family is identified from the total produced time for all products. After having selected a product family, the next step is the selection of machines that are shared by products belonging to different families. This is viewed as a constraint for the fulfilment of a cellular layout and brings to external sharing because the products are processed in different cells. Subsequently there is the identification of the main value stream starting from the main critical value stream analysis and then extend to the other branches. After that, the value stream mapping of the factory's current state has to be designed. Current state follows a

[1] Cycle Time is the time needed to finish one process step of a single product unit.
[2] Changeover is the process of converting a line or machine from running one product to another.
[3] A product family is typically a group of products that share a common processing sequence (cutting, printing, embroidery, sewing, washing and finishing) and, in some cases, the same type of machinery.

product's production (materials) path from beginning to end, drawing every process, material and information flows, including materials retention, which will demonstrate the throughput time[4] of first bundle from "door to door"[5]. The design of the value stream mapping follows a set of standard symbols to represent processes and flows. Once the current map has been drawn a deep analysis of waste has to start. Finally, it is necessary to draw a future state map of how value should flow applying the lean tools and improvements. The main changes are related to:

- the takt[6] time for the synchronization of the pace of production with the pace of sales,
- the development of continuous flow whenever possible,
- the application of the pull logic with the implementation of supermarkets and to the levelling of the production mix.

After the specification of value and the mapping of value stream without waste, the company has to make the operations flowing smoothly with no interruptions, delays, or bottlenecks. This situation can be achieved with the conversion from department and batches to product teams and flow. The implementation follows three steps:

1. The company has to focus on the specific design and product itself and do not let it out of sight from beginning to conclusion.
2. The firm has to ignore the traditional boundaries of jobs, careers and functions to form a lean enterprise, removing all impediments to the continuous flow.
3. The company has to create new practices and standards that eliminate backflows, scrap etc. so that the production can proceed continuously.

With this approach completing the entire production process requires much less time, and the production will start only on demand. Indeed, the pull method limits production to those parts demanded by the next downstream process.

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[4] The throughput time is the period required for a material, part, or subassembly to pass through the manufacturing process.
[5] The typical VSM is called a "stock to dock" or "door to door" value stream map since it normally covers the information and process flow for the value stream at your facility, including shipment to the plant's customer and delivery of supplied parts and material.
[6] Takt time is the average time between the start of production of one unit and the start of production of the next unit, when these production starts are set to match the rate of customer demand.

These processes has to be optimized constantly during time, until reaching a complete elimination of waste. Perfection can be achieved first with transparency and then applying a combination of *kaikaku* (radical change) and *kaizen* techniques. Transparency means that all the processes can be "seen" simply being on the floor using a set of visual controls such as *andons*[7], *heijunka* boards, and space markings that make the process performance "transparent." With these tools, managers can immediately understand if the process is performing as designed, and if not, from which area the problem comes from.

However, the transformation of processes is not enough if the entire organization does not change simultaneously. Managers have to focus also in the implementation and adoption by employees of a new culture and a new way of thinking. The transformation process also combine a managerial model based on:

- Values: respect for others, sharing and communications
- Attitudes: restraint, perseverance, results orientation
- Methodologies: leader who becomes teacher[8]
- Instruments: 5S, Value Stream Mapping, Kanban.

Lean management is not only a mere implementation of instruments; it is mainly a managerial philosophy, a system of values and behaviour, that, after being interiorized, they will build the firm culture. This new type of thinking has to be implemented to the entire organization for a complete transformation of the company, in particular managers and executives has to face three fundamental business issues (Lean Enterprise institute, What is Lean?):

- Purpose – What customer problems will the enterprise solve to achieve its own purpose of prospering?
- Process – How will the organization assess each major value stream to make sure each step is valuable, capable, available, adequate, flexible, and that all the steps are linked by flow, pull, and levelling?

[7] A warning device, normally a light, to signal an abnormality, it is a part of the system of transparency.
[8] Sensei-ing is clearly more powerful and useful to the company than consulting. For one thing, the impact on the business trajectory is much larger and for another, clients being sensei'd learn how to solve their own problems in a wide variety of situations, so they rarely revert to not-knowing when a new problem arises.

- People – How can the organization ensure that every important process has someone responsible for continually evaluating that value stream in terms of business purpose and lean process? How can everyone touching the value stream be actively engaged in operating it correctly and continuously improving it?

1.2. The Toyota Production System

Between the 50s and the 60s an engineer named Eiji Toyoda and a production genius Taiichi Ohno, after a deep analysis in the US' mass production system, invented a new production method that was in line with the characteristic of the Japanese dimensions and constraints, which the US market did not possess.

From that moment was invented the Toyota Production System (TPS) that empowers team members to optimise quality by constantly improving processes and eliminating unnecessary waste in natural, human and corporate resources. This system has the prerogative of using different instruments to find, reduce and in some cases eliminate each sort of waste (*muda*), which permeates the entire organization. Toyota Production System influences every aspect of the organisation including the set of values, knowledge and procedures. It entrusts employees with well-defined responsibilities in each production step and encourages every team member to strive for overall improvement.

As a result, this system, which can be represented as a house (fig. 1) that delivers the following key benefits[9]:

- Quality inherent in Toyota's products
- Costs are kept to a minimum thanks to a good return on investment
- Delivery on time, and to the expected standard, allowing Toyota's customers to plan and maintain their operations successfully
- Environmental concerns are shared by Toyota and its customers, from manufacturing through to recycling at end-of-life

[9] The TPS House has received many implementations during years, and the benefits increased during time. Originally, the aim of the TPS was "doing more with less"; that is to say producing the best quality with the lowest cost and the shortest lead-time.

- Safety is Toyota's constant concern – both for its employees and for those of its customers.

All these goals cannot be achieved if the company has not a high level of stability (basement) obtained with standardized work, kaizen and Total Productive Maintenance (TPM) and two important pillars: Just in Time and *Jidoka*.

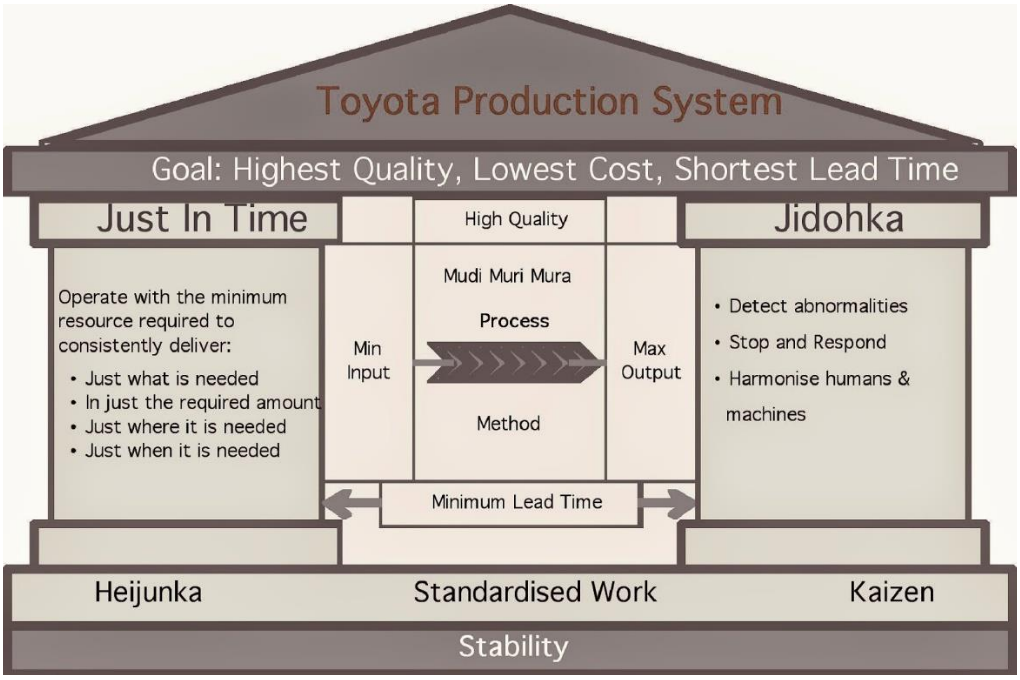

Figure 1: Toyota Production system "House"

1.2.1 The Types of *Muda*

Search and remove *muda* is at the base of the lean philosophy, despite seemingly a simple principle, eliminating waste, is not an easy task. In particular, the most difficult part is about identifying and highlighting it. A proper waste measurement system can overcome these issues.

There are three main conditions for effectively working waste measurement system (Pienkowski M., 2014):

1. Complex waste identification, which facilitates elimination of root causes of waste not only symptoms. Putting emphasis only on visible issues, leads to the situation, where achieved improvements are temporary and the problems are back over time.

2. Using quantified waste metrics, which allow proper control of a process. Calculating them helps with monitoring and highlighting all problems and defects within a process. It also enables company to compare the results from different areas.
3. Developing response standards for all detected problems, which support and accelerate the decision making process. Properly introduced, standards should ensure careful analysis of a root cause and quick implementation of mistake-proofing solutions.

If these conditions are not met the ability of the company to reduce waste decreases drastically.

Muda is an activity that does not add value to the product, and the TPS recognize three different types of waste: *Mura* (unevenness), *Muri* (overburden) and already mentioned *Muda* (waste).

The first is *Muda* that refers to waste created by unnecessary activities or every human activity that absorbs resources but does not create value for customers. Taiichi Ohno (1912-1990) identified seven types of *Muda* that are (Taiichi O., 1988):

1. Over-production – producing more than requested by the demand. This is the worst form of waste because it contributes to the other six.
2. Waiting – operators' waiting the machine cycles or waiting for the approval of a document or needed parts fail to arrive etc.
3. Transport – moving materials and products from one place to another.
4. Over-processing – performing activities that do not add value to the product maybe because they are unnecessary or incorrect.
5. Inventory – handling unnecessary stocks in the form of WIP, raw materials, finished goods, documents etc.
6. Defective goods – inspecting production to find defects, rework of defected products.
7. Motion – making movements that are unnecessary or wasteful, such as components that are "far away" from the machine, documents that are «out of reach» etc.

During time, the number of wastes have increased due to the application of lean thinking in other sectors and firms, for example in firms that produce services. These “new” wastes are (Bicheno J., 2008):

- Making the wrong product to be efficient, human capital, inappropriate systems, energy and water, and natural resources.
- Seven wastes in customer service – delays, duplication, unnecessary movement, lack of clarity in communication, wrong inventory, missed opportunities and mistakes.
- Fourteen office wastes – screening and research, inappropriate measurement, low load, high load, inappropriate prioritization, interference, inappropriate frequency, start-up and end off, mistakes, errors or lack of appropriate knowledge, communication error, sub-optimization, wait, improper presence and inappropriate trade off.

Second, there is *Muri*, means absurd or unreasonable, which is an unnecessary or unreasonable requirement, used in processes that perform poorly. This waste is due to the overload of equipment that put employees and machines into stress, reducing their performance. This problem appears when the company is not able to managing correctly sequencing, scheduling and loading[10] to perform activities. Looking into details there are three main causes of *Muri*:

1. Lack of standardized operations – this will affect both employees, who will do unnecessary operations due to unclear instructions and poor communications, and equipment that will not receive enough maintenance standards and inappropriate utilization.
2. Poorly organized workstations – wrong designed layout that force employees to put more effort than necessary.
3. *Mura* – variation in production.

This excessive stress of people and machines may result in defects and delays of the processes but also in breakdowns of the machines and in increase of absenteeism.

[10] Sequencing means in which order to process things, Scheduling when to perform things and Loading how much to do.

The last type of waste is *Mura* that means lack of consistency, variation or unevenness related to the production volume. This squandering is created by the retention of the batch logic as a way of reducing costs per unit and maximizing the utilization of key resources. The negative effects of this type of waste are similar to a lack of dependability[11]. This logic adopted to compensate the variability of the demand has the result of increasing the fluctuations of production. This phenomenon is called bullwhip effect (fig. 2), a situation where a small variation in demand at the end of the value stream (customer) leads to high changes in production volume in the earlier stages (production processes).

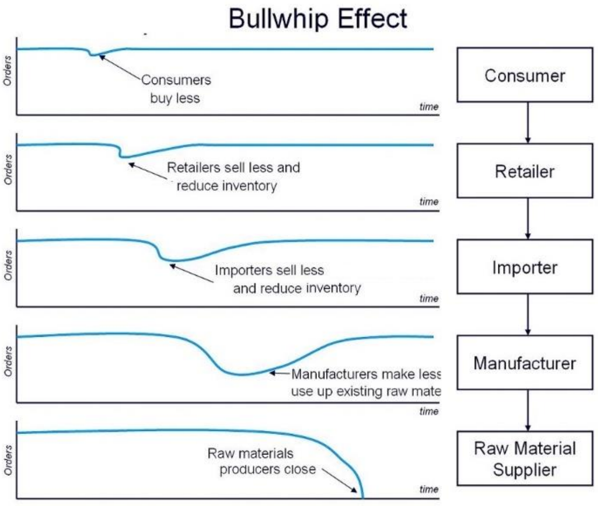

Figure 2: Bullwhip effect (http://taskoconsulting.com)

The main goal of lean philosophy is to recognize and eliminate each type of waste considering as barriers to Just-in-Time system. To achieve a complete identification of the tree types of waste the company has to understand deeply the correlations that exist between *Muda*, *Muri and Mura* (fig. 3). The variation of production (*Mura*) is the main cause of the overproduction, which will subsequently cause all the other types of *Muda*, and *Muri* (Pieńkowski M., 2014).

[11] Dependability is one of the five operations performance objectives and means to do things on time. The others are quality, speed, flexibility and cost.

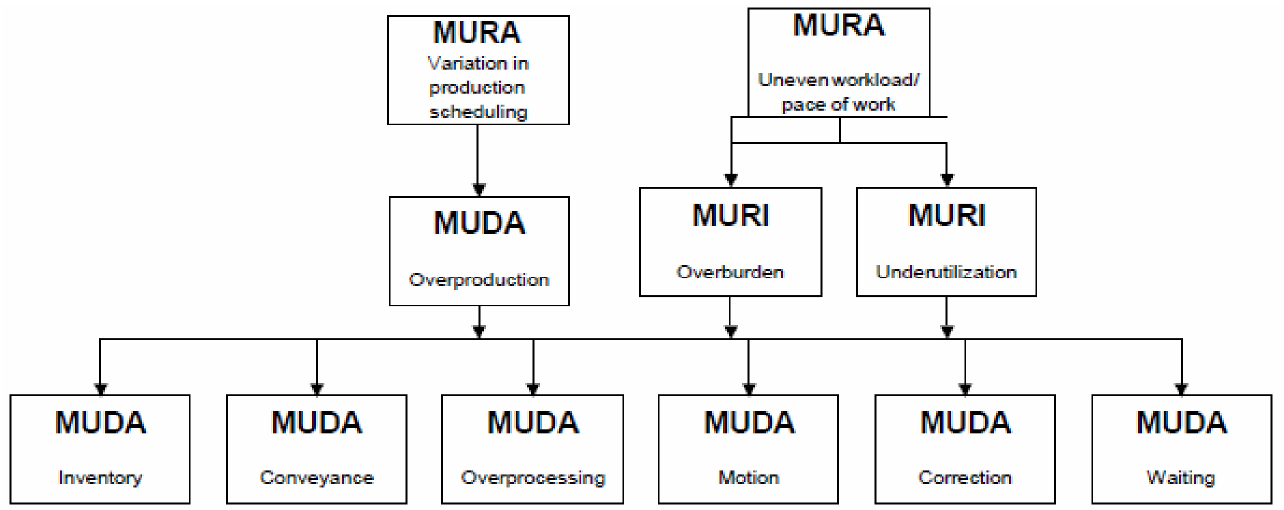

Figure 3: Correlations between Mura, Muda and Muri (Pieńkowski M. 2014)

The way of recognizing waste starts from a measuring current and desired values for the three Mu's which are a good discriminant of company's lean maturity. These metrics are divided into two different categories: passive waste (which refers to waste in standards) and active waste (which refers to waste in action) to differentiate the squandering during planning to the waste during the production process.

At planning level, managers, who are not able to design correctly the steps of the processes, are who create errors. The waste is calculated for each value stream and has three levels of analysis:

1. Operator level – waste in each step performed by one operator
2. Process level – waste in all steps performed to obtain a process. It lines up with the operator level if the process consist of only one operator.
3. Value stream level – waste in all processes that are necessary for the value stream.

All the improvements achieved has to be calculated in terms of:

- C/T – Cycle Time of all process steps, where Cycle Time is understood as time needed to finish one process step of a single product unit,
- NVA – time of Non-Value Added steps of each process
- T/T – Takt Time of a value stream, where Takt Time is understood as the available production time divided by customer demand.

Looking at the production level the identification of waste should be done using active metrics and measure them more often than passive ones. A continuous measurement is the proper way for the analysis of abnormalities and for a promptly correction. The information needed to calculate the active metrics are:

- DL – daily Direct Labour Time of each process
- S/T – Standard time of each process, where Standard Time is understood as expected time needed to finish particular production process.
- A/T – daily Available Time of each process, where Available Time is calculated as number of shifts multiplied by 8 hours minus planned breaks and downtime.
- D/T – daily unplanned Downtime of each process.
- R/T – daily Rework time.
- WIP – daily Work-In-Process in a process.
- SWIP – standard daily Work-In-Process in a process.

All that measurements are ineffective if the company has not a responsive method of actions and decisions to correct planning and production to eliminate waste. The lean thinking philosophy has developed a response standard called PDCA (Plan, Do, Check and Act) that is an improvement cycle based on the scientific method of proposing a change in a process, implementing the change, measuring the results, and taking appropriate action (fig. 4). This approach is also known as the Deming Cycle or Deming Wheel after W. Edwards Deming, who introduced the concept in Japan in the 1950s. All five steps of the response standard are described below with more details.

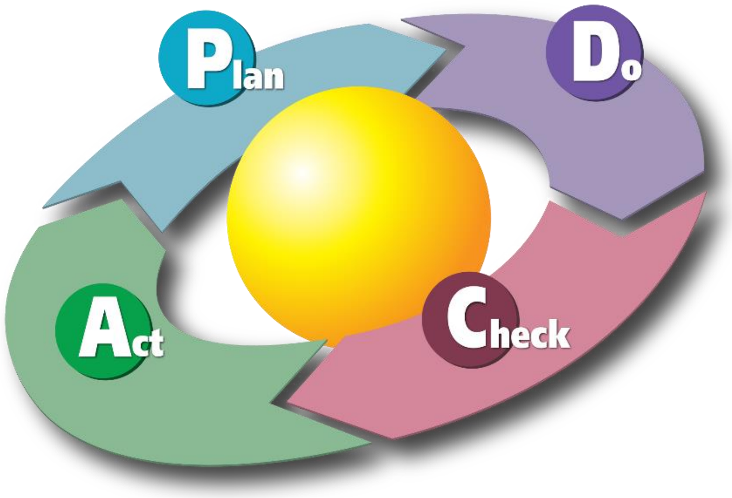

Figure 4: The response process standard, PDCA.

- Initiation – It's the first step and it's the discriminant of starting the PDCA cycle. For each metric analysed above the company has to set a borderline, so when a value is below or above the accepted value the response standard starts.
- Plan – It consists of collection and analysis of data to formulate a plan of actions to improve the performance. These countermeasures are proposed after having analysed the reasons of the problem and found the root cause. This can be achieved using some tools like the 5Why's[12], Ishikawa Diagram[13] or Brainstorming.
- Do – After that, the plan is agreed it has to be implemented as soon as possible, nominating someone who is responsible for timing and correct implementation.
- Check – In this phase, the company has to analyse if the action pursued have obtained the expected results. The firm uses the values of waste metrics comparing before and after the implementation.
- Act – At this point, the change is standardized if it has been successful, but it has to be monitored and constantly improved. If the change has not been successful, the lessons learned from the 'trial' are formalized before the cycle starts again.

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[12] A problem solving method, which employs the technique to continue to ask "Why?" to explore the cause and effect relationship, in an attempt to find the root cause.

[13] A diagram that shows the causes of an event and is often used in manufacturing and product development to outline the different steps in a process, demonstrate where quality control issues might arise and determine which resources are required at specific times. Kaoru Ishikawa developed the Ishikawa diagram during the 1960s as a way of measuring quality control processes in the shipbuilding industry.

After this point, the cycle starts again and defines the problems, which are preventing further improvement.

The PDCA technique can be visualized in the A3 approach, dividing the common A3 sheet paper (11-by-17 inches) into the following elements:

- Title— Name the problem, theme, or issue.
- Owner/Date— Identify who "owns" the problem or issue and the date of the latest revision.
- Background— Establish the business context and importance of the issue.
- Current Conditions—Describe what is currently known about the problem or issue.
- Goals/Targets— Identify the desired outcome.
- Analysis— Analyse the situation and the underlying causes that have created the gap between the current situation and the desired outcome.
- Proposed Countermeasures — Propose some corrective actions or countermeasures to address the problem, close the gap, or reach a goal.
- Plan — Prescribe an action plan of who will do what when in order to reach the goal.
- Follow-up — Create a follow-up review/learning process and anticipates remaining issues.

The A3 is like a *résumé* that can be adapted in layout, style, and emphasis according to the person seeking the job and the type of job being sought. Practitioners can adapt the format to fit the requirements of each situation. All the evaluations about company problems has to be analysed looking to *gemba*[14], which is the place where value-creating work happens.

Alternatively, a company can use the DMAIC (Define, Measure, Analyse, Improve and Control) cycle, made popular by the Six Sigma approach. Looking into more detail it consists of:

- Define the problem – In this phase, the leaders of the project create a Project Charter[15], create a high-level view of the process, and begin to understand the needs of the customers of the process.

[14] Gemba walk denote the action of going to see in production the actual process, understand the work, ask questions, and learn.

[15] The Project Charter is an official, basic document that outlines a process improvement project. It is the first step in a Lean Six Sigma project, and therefore takes place in the Define phase of DMAIC. However, it can be periodically reviewed, refined, and revised throughout the project.

- Measure – The firm validates the problem and tries to understand the root cause for waste in the process. After having highlighted the cause, responsible for improvement has to collect data about these problems.
- Analyse – At this point the data collected have to be analysed, a team analyses both the data and the process to narrow down and verify the root causes of waste and defects.
- Improve – A team search for ideas that can remove the causes of defects and waste, solutions are tested and those solutions that seem to work are implemented, formalized and results measured.
- Control – Here the firm has to maintain the best solutions monitoring and controlling processes constantly to check that the improved level of performance is sustained.

The goal of Six Sigma is to struggle for perfection by reducing variation and meeting customer demand. Reducing variation is possible if the company understands the root cause and where the variation comes from in the process and why. Six Sigma and lean both deal with predicting processes to reduce waste and variation, where lean utilizes a visual method; instead, Six Sigma utilizes a statistical approach. Six Sigma provides a clear change of structure and is much more orientated on fast and tangible results in comparison with Total Quality Management (TQM), TPM, and lean.

These standard responses are often supported by some visual techniques, whose function is simplifying the identification of *Muda, Mura* and *Muri* and accelerating the process of improvement. One of the most common visualization tool is the *Yamazumi* chart, a stacked bar chart that shows the source of the cycle time in a given process. *Yamazumi* is a Japanese word that means “pile” or “stack”. Therefore, a stacked bar chart represents process tasks. Each pile can be categorized as either Value Added, Non-Value Added or Waste (fig. 5).

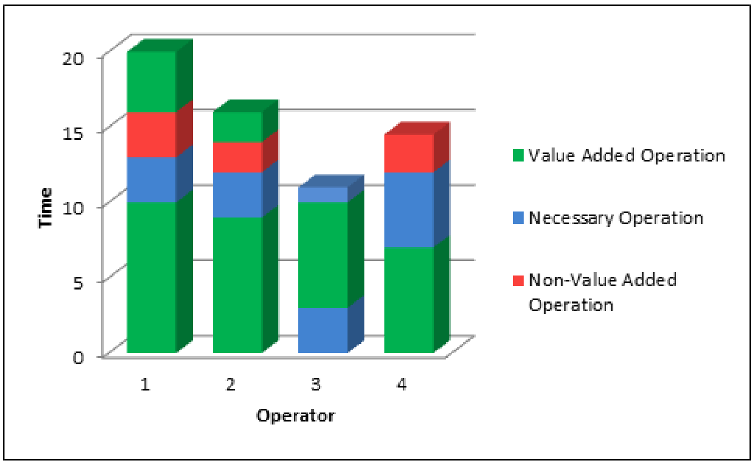


Figure 5: Yamazumi chart (leanmanufacturing.com)

The *Yamazumi* chart is used mostly to balance processes and create continuous flow, allowing a visual indication of which operations are overloaded, and which are underutilized. This tool has many benefits:

- Visual – Workers and operators immediately and intuitively can see where the delays are coming.
- Simple – *Yamazumi* Board tells the story at a single glance.
- Public – This system is a great motivator to positive performance improvement.
- Decision support – It can see where the key constraint, the key roadblocks are.

It is also a perfect tool to visualize passive waste metrics of Mura, Muri and Muda:

- Mura – *Yamazumi* chart visualizes variation in workload in a single process or a whole value stream.
- Muri – *Yamazumi* chart visualizes the potential overload and underutilization of each operator.
- Muda – *Yamazumi* chart distinguishes between value added and non-value added steps of a process.

Following the waste response standards requires strong discipline from employees, especially management. It is their role to regularly monitor the waste metrics values, initiate analysis and ensure the implementation of corrective actions. This activity should become part of their daily routine. Thanks to the consequence and regularity of the management, a culture of problem solving will grow within employees. It will prevent the situation where detected abnormalities are ignored or overlooked. Following the response standards is a true key to continuous improvement within a company.

1.3 TPS Structure

1.3.1 The first pillar – Just in Time

The Just-in-Time (JIT) concept aims to produce the right products, at the right time, in the right amount with the minimum necessary resources. This system reduces the level of inventories at minimum and eliminates the problem of overproduction. The "sea" of inventory (fig. 6) covers all the problems in the production process, so a reduction of it keeps afloat all type of waste and make it visible. This notion of surfacing problems and abnormalities is a critical concept in TPS. JIT have three basic elements to change the production system of company:

- Continuous flow, where is used the concept of manufacturing cell to allow materials to flow in the process and improve the communication among operators,
- Takt time, this marks the production rate within the process,
- Pull System, which allows the flowing of materials/products without any stock, or within a minimum range of work in progress.

Figure 6: Inventory hides waste

Pull & Kanban

The pull system is a key element of the Just-in-Time philosophy and consists of limiting production to those parts demanded by the next downstream process. To better managing the pull system a firm, adopting lean, uses a production control method called *Kanban* or supermarket. *Kanban* (fig. 7) is generally recognized as a card that passes between processes, communicating information as to what materials to replenish. The APICS Dictionary, 13th ed. (The Association for Operations Management, Chicago, 2010) defines *Kanban* as "*a method of just-in-time production that uses standard containers or lot sizes with a single card attached to each.*" The objective of this production aspect is to balance workflow by signalling production of a part, component, or subassembly only when the next operation in the process has begun work on the unit or lot previously produced. The second part of the APICS definition of *Kanban* is *"... a pull system in which work centres signal with a card that they wish to withdraw parts from feeding operations or suppliers*." (The official supply chain dictionary, 2014).

The application of this system takes several benefits:

- Agility – Pull system responds quickly to the variability of the demand.
- Reduces waste – Minimize the risk of overproduction and eliminate unnecessary inventory.
- Low cost – *Kanban* is a very cheap visual tool.
- Improves productivity – *Kanban* synchronizes all steps in the process.
- Simplicity – *Kanban* system provides clear manual-visual control process.
- Improves communication – maintain a visual communications between departments (cells) in the factory.

There are three types of *Kanban* cards:

1. Move *Kanban* – a license to retrieve parts from the previous process that is responsible for producing the item.
2. Production *Kanban* – a license to the previous process for replenishment to produce the item.
3. Supplier *Kanban* – a license to an outside supplier to deliver more parts to the process that is using supplier components.

A typical *Kanban* card provides:

- Supply information: Supplier name and number (vendor code) and stocking location
- Part information: ID number, description, quantity
- Customer information: User group and location, storage locations, *Kanban* number.

Figure 7: Fischer Kanban

To apply correctly the *Kanban* model workers have to follow six rules (Wilson L., 2010):

1. Later process goes to earlier process and picks up the number of items indicated by the *Kanban*.
   Function: Creates pull, provides pick up or transportation information. The replenishment concept is formed here.
2. Earlier processes produces items in a quantity and sequence indicated by the *Kanban*.
   Function: Provides production information and prevents overproduction.
3. No items are made or transported without a *Kanban*.
   Function: Prevents overproduction and excessive transportation.
4. Always attach a *Kanban* to the goods.
   Function: Serves as a work order.
5. Defective products are not sent to the subsequent process.
   Function: Prevents defective parts from advancing; identifies defective process.
6. Reducing the number of *Kanban* increases their sensitivity.
   Function: Inventory reduction reduces waste and makes the system more sensitive.

Cell Layout

A revolutionary aspect of the lean system is the adoption of a different form of layout: the cell. A cell is a combination of people, equipment, and workstations organized in the order of process flow, to manufacture all or part of a production unit and it has these characteristics:

- One-piece, or very small lot, flow
- Is often used for a family of products
- Has equipment that is right-sized and very specific for this cell
- Is usually arranged in a C or U shape so the incoming raw materials and outgoing finished goods are easily monitored
- Has cross-trained people for flexibility

The first advantage of cell is the reduction of waste, in particular transportation and inventory, but also the speed up of the process and the flowing of components. In addition, the use of smaller machines brings to a deep improvement in flexibility and responsiveness. This is achieved with the U-shaped layouts that are generally the most efficient since they provide the shortest distance for time travelled. Work also enters and exits at the same vicinity, while communication is increased and flexibility can be completed by different operators being able to be cross-functional. A modified circle is also another option, which has the same premises of the U-shaped layout.

Single Minute Exchange Die

Single Minute Exchange Die (SMED) is a method for reducing waste, improving the changeover between the manufacturing of the current product to the next one. This tool is in line with the JIT principle because, with its implementation, the company reduces the batch produced and improves the flow of products. Originally SMED was developed to improve die press and machine tool setups, but its principles were applied to changeovers (fig. 8) in all type of processes. SMED represents the setup time of the machine to change completely the production in the shortest time possible. The changeover improvement is a response to external factors like the demand variability or the reduction of product life cycle and to internal optimizations like the reduction of inventory.

The implementation of the SMED is complex and the process is composed of four stages (Sohani D., Yave D., 2012):

1. Observe the current methodology – Current procedures generally recorded on video tape of all the changeover process. It covers the complete changeover from one model to another model.
2. Separate internal and external activities – Internal activities are those that can only be performed when the process is stopped, while External activities can be done while the last batch is being produced, or once the next batch has started.
3. Converting internal setup to external setup – Pre-prepare activities or equipment while the machine is running, make the changeover process flexible and speed up the required changes of equipment.
4. Continuous Training – After the successful first iteration of SMED application, the prime requirement becomes the training of all the operator of the cell.

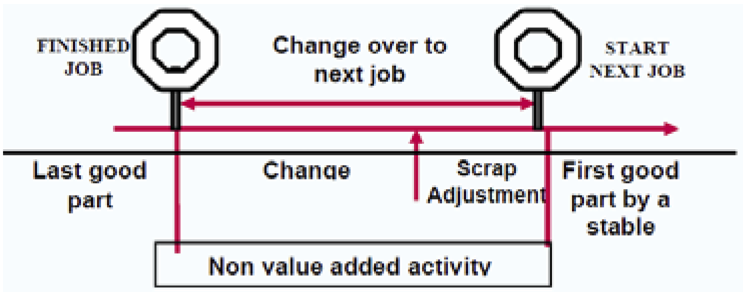


Figure 8: Representation of changeover time (Berna U. 2011)

1.3.2 The second pillar – *Jidoka*

Jidoka can be explain as human automation in which the worker sets up the workpieces, presses the ON switch, and leaves the machine to do the processing. The machine itself will detect when a defect has occurred and will automatically shut itself off. In some cases *jidoka* consist of auto-input (auto-feed) and auto-output (auto-extract) devices, so workers become unnecessary. For applying *jidoka*, the company has to look at the operations and separate which are done by the humans from which are done by the machines. After that there is a gradually increase of the machine work at the expense of the human work. This will increase the productivity and reduce costs, but also permits enough flexibility to respond to the changes in customer demand. The development of defect-prevention devices for automated equipment is the heart and soul of *jidoka*, machines will stop themselves, and sound an alarm to inform employees about abnormalities, so a single worker can be responsible for a higher number of machines simultaneously. By stopping the production as soon as a problem occurs, employees are protected, damage to equipment and tools that might otherwise cause significant downtime for repairs are prevented, and producing parts that may not meet the quality standard are avoided. When the machine signals a defect, the *andon*[16] problem display communicates abnormalities to the team leader who will work to resolve it and restart the production as soon as possible. After having resolved the issue, the employees have to understand its root cause, and find the right countermeasures to ensure that the problem does not recur in future.

1.3.3 The basement

Heijunka

Heijunka is a Japanese word for levelling, specifically levelling production, which means stabilizing the rate in a narrow band; no large ups or downs in rate. With this method, each single product can be produced in a shorter time. With *heijunka* a process is designed to switch products easily, producing what is needed when it is needed, and relying on production. The establishment of a level-average demand rate accommodates any variation in volumes. The main benefits of producing a levelled mix of products are:

- Short lead time[17]
- Reduced inventories
- Lower opportunities for defects
- Minimum idle time and/or overtime

Many firms adopts the *heijunka* box that is a visual scheduling device that is utilized in production levelling. The box is a tool that is used in attaining the goal of production smoothing. This box is a wall schedule that is divided into a grid of boxes in which every column of boxes pertains to a particular time period and lines are being drawn down the grid

[16] *Andon* is a manufacturing term referring to a system to notify management, maintenance, and other workers of a process or quality problem. It is usually a lighted overhead display easy to see from each side of *gemba*.

[17] The lead-time is the time from the moment the customer places an order (the moment you learn of the requirement) to the moment it is ready for delivery.

in order to visually partition the schedule into several columns of individual shifts or days. The *24anban* cards are placed on the box to provide a visual representation of the upcoming production runs. One of the advantages of the *heijunka* box is to help in easily determining what type of jobs are being queued for production and for what particular day they are being scheduled.

Kaizen

Masaaki Imai (1986) gives the definition of kaizen: *"Kaizen means improvement. Moreover, it means improvement in personal life, home life, social life and work life. When applied to the workplace, kaizen means continuing improvement involving everyone – managers and workers alike."* In continuous improvement, it is not the rate of enhancement, which is important; it is the momentum of renovation. It does not matter if successive improvements are small; what does matter is that every month (or week, or quarter, or whatever period is appropriate) some kind of improvement has actually taken place. To be achieved correctly the implementation of *kaizen* follows a six-step process:

1. Discover improvement potential – this is the most important step during which the company has to underlying waste and highlighting the enhancement potential. Here workers need to discover and "see" waste, inefficiency, problems and areas of improvements. However, they will not find out if they have not the right attitudes (Kato Isao, 2011):
    - Always practice a relentless spirit of inquiry and obtain facts from the actual source or process you are studying;
    - Do not be swayed by preconceived notions or what we jokingly like to call your internal "urban legends";
    - Practice rigorous and thorough observation of the process you are studying;
    - Conduct *Kaizen* with a calm and rational attitude

    Maybe they have not the right skills (Kato I, Smalley A., 2011):
    - Classify and organize;
    - Quantify the observations;
    - Specify the details.

2. Analyse current methods – each company can choose different methods of analysis for work-related processes. The most fundamental tools available for analysis are process flowcharts, time study, motion analysis, and work element analysis.
3. Generate original ideas – to have disruptive ideas the company has to eliminate all the roadblocks to creativity as habits, preconceptions, not invented here syndrome, and start to generate as many ideas as possible without worrying about judgements. The most famous method that enhance ideas is brainstorming, a procedure in which participants in groups work together to generate original ideas and identify new solutions. Brainstorming seeks to take advantage of the energy of the group to build a chain reaction for idea generation.
4. Development an implementation plan – Who will do what, where, how, by when and why are fundamental questions that have to be answered whether the plans are thought through or written down on paper.
5. Implement the plan – Change drives a need for some form of training in most cases. If only the people participating in *Kaizen* activities are aware of and participate in the change, then its impact will probably not be as great as expected.
6. Evaluate the new method – This step involves verifying whether improvements have actually occurred and then standardizing the practices that have been improved.

2.2.4 The roof

Total Quality Management

Feigenbaum introduced TQM in 1951 by the name total quality control (TQC). Quality, using his words is "*the total composite product and service characteristics of marketing, engineering, manufacture, and maintenance through which the product and service in use will meet the expectations of the customer*" (Feigenbaum A. V., 1983). The concept of Total Quality Management (TQM) is strictly connected with the *kaizen* approach and TPM concept because maintenance has a fundamental role in quality. It has an impact in all of the three properties in the eyes of a customer: quality, price and delivery time. Total Quality Management has the goal of achieving total quality through everybody's participation and is "*an effective system for integrating the quality development, quality maintenance and quality improvement efforts of the various groups in an organization so as to enable production and service at the most economical levels which allow for full customer satisfaction*" (Feigenbaum A. V., 1983).

Higher quality both should and can be achieved through:

- Internal quality improvements.
- External quality improvements.

Internal improvements are related to make the processes "leaner", instead external are aimed at the external customer, the aim being to increase customer satisfaction and thereby achieve a bigger market share and with it, higher earnings. To achieve better performance TQM analyses all costs associated with quality that can be divided into prevention costs, appraisal costs, internal failure costs and external failure costs.

- Prevention costs are those costs incurred in trying to prevent problems, failures and errors from occurring in the first place.
- Appraisal costs are those costs associated with controlling quality to check to see if problems or errors have occurred during and after the creation of the service or product.
- Internal failure costs are failure costs associated with errors, which are dealt with inside the operation.
- External failure costs are those, which are associated with an error going out of the operation to a customer.

Relationship between TQM and TPM

The relationship between TPM and TQM has been studied from various perspectives. First, they have a common objective of improving business performance. They can be considered complementary because TQM has a focus on the quality of output, while TPM is more oriented to machine performance. These two approaches can be implemented individually or simultaneously. In the last case, researchers have analysed higher gains (McKone, 1999). These gains are both external and internal. Internally, the improvement of quality brings to higher productivity and a reduction of costs. If the company competes on prices this approach is necessary. Externally, higher quality makes the satisfaction ratio higher and improves customer loyalty. Consequently, the company achieve higher market share and higher profits.

Chapter 2

Total Productive Maintenance

2.1What is Maintenance?

Maintenance is defined as "*combinations of all technical and administrative actions intended to retain an asset or a system in, or restore it to, a state in which it can perform the required functions*" (Peng K., 2012).

Contrary to the common idea of "fixing" breakdowns, the role of maintenance is to prevent all losses caused by machines or system-related problems. The mission of maintenance is to achieve:

- Optimum availability – Maintenance department has to ensure that the equipment are always in good operating condition, so the production capacity remains stable and high.
- Optimum operating conditions – Availability is only one component in the Overall Equipment Effectiveness (OEE), so the focus of maintenance should be also on reliability (speed) and performance (quality).
- Maximum utilization of maintenance resources – The maintenance organization should effectively utilizes the resources of the total operating budget.
- Optimum equipment life – The role of maintenance programs is to reduce maintenance costs by expanding the useful life of all plants assets.
- Minimum spares inventory – A good maintenance management has to be able to anticipate the need of a specific component for each machine to reduce the level of spares inventory and consequently holding costs.
- Ability to react quickly – The maintenance organization must be able to react quickly to the unexpected failure.

Levitt says that the "*mission of the maintenance department is to provide reliable, safe physical assets and environments and excellent support for its customers by reducing and eventually eliminating the need for maintenance services*" (Levitt J., 2011). All the maintenance activities have the objective of improving firm profitability. Profitability can be defined as the product of productivity and price recovery. Productivity is the ratio of quantity realized to the sum of all inputs necessary to produce. Price recovery is the ratio of the price of the products to the costs of the consumed inputs.

$$Profitability = Productivity \times Price\ recovery$$
$$= Output/Input(s) \times Price/Cost(s)$$

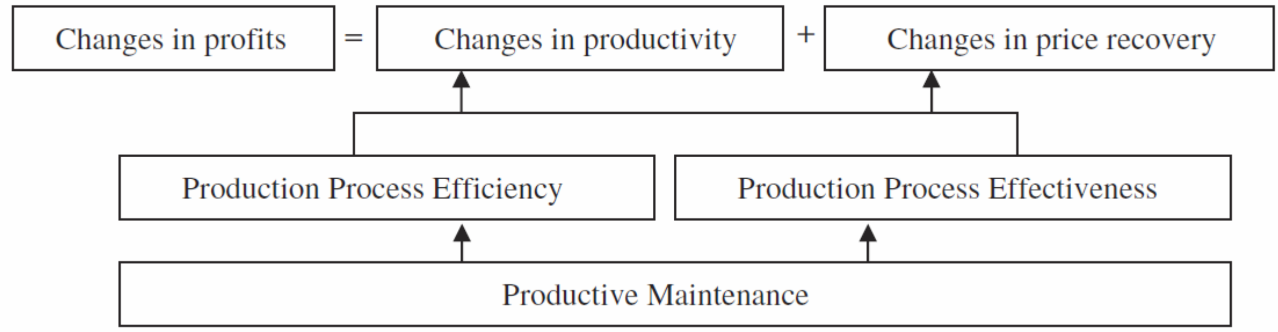


Figure 9: Maintenance impact on firms' profits (Alsyouf I. 2007)

As we can see in fig. 9, maintenance affects both production efficiency and effectiveness. An effective maintenance policy have many impacts on the firm. First of all an enhanced utilisation of equipment brings to higher quantity produced with good quality (fig. 10, position 1). Inevitably, there is an increase of the profit margin due to a reduction of manufacturing costs (position 2). In the long run a reduction of inventory, Work in progress (WIP) costs and buffer have an impact on manufacturing costs (position 3). Finally, an enhanced quality transforms into a higher customer satisfaction and necessary an increase of prices (position 4).

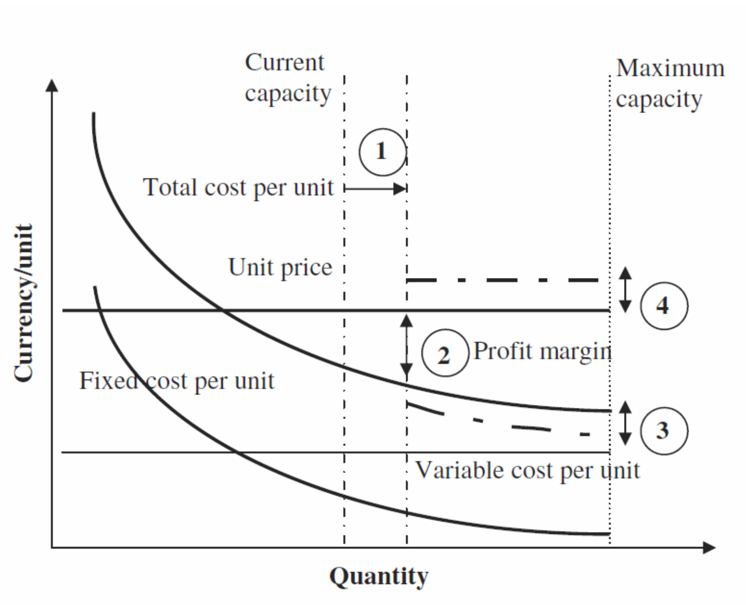


Figure 10: Quantity and quality product produced and total costs per unit (Alsyouf 2007).

In reality, not all the maintenance approaches have a positive impact on performance. Literature says that proactive and aggressive[18] maintenance strategies are associated with improved performance while reactive is associated to lower performance. The study of Swanson sustains this thesis (Swanson L., 2001).

2.2 Issues of maintenance

One of the key objectives of maintenance is extending the equipment life, but the rapid development of technology obsolescence has reduced the importance of this objective. In many industries, the replacement is performed mainly for the adoption of new technologies or new products. Although Total Productive Maintenance (TPM) had been a significant progression that revolutionized the concept of machine management, it has its incompleteness due to its limited focus on diminishing defects and breakdowns. Furthermore, another goal of maintenance is improving the OEE, in particular the availability of machines. This goal has to be achieved if the utilization ratio of equipment is very high, even if the improvement is not necessary. In addition a good maintenance worker

[18] An aggressive maintenance strategy, like TPM, goes beyond efforts to avoid equipment failures and seeks to improve overall equipment operations.

is evaluated on the number of breakdowns adjusted and troubles resolved, that is in contrast with the factory goal that, to increase productivity, want to achieve a result of 0 breakdown. Another issue of maintenance is its organizational structure. Sometimes there are two different departments; one concerns the equipment utilization (production), the other makes sure of equipment availability (maintenance). In some cases, there is also the engineering department that is responsible for machines selection, development and upgrades. This fragmentation creates some conflicts and in many cases, the maintenance department does not have a total control on equipment. Finally, maintenance considers the upkeep activities to be performed in stable environment in which machines operate for a long time. In reality, the technology continues to evolve over time and consequently the environment is dynamic, so it is very difficult to achieve an adequate maintenance program before the equipment has been replaced. In this situation, only a good communication of variations in production to the maintenance department and a continuous improvement of workers' skills are necessary to correctly manage and improve upkeep activities.

2.3 Types of maintenance

TPM is the development of five subsequent stages of maintenance management and of the fields of reliability. Reliability is an engineer discipline that have three different approaches: mission reliability, maintainability and availability. Mission reliability is the probability that something will work without breakdown for a specific activity under stated conditions of use. Maintainability is the probability that a component will be restored. Availability is the probability that an equipment will be capable of performing its mission in time. As explained before, reliability is a probability (always between 0 and 1), and the most common measure is the relative frequency of breakdown. Maintenance management and reliability together concern not only with equipment but also with technical, operational, and managerial activities required to sustain the performance of manufacturing equipment throughout its entire lifetime. Maintenance management has been based on mathematical models and statistical analysis of equipment. The five different approaches of maintenance management are:

- Breakdown Maintenance or run-to-failure management
- Preventive Maintenance

- Predictive Maintenance
- Corrective Maintenance
- Maintenance Prevention

Breakdown or reactive maintenance

The breakdown management phase started in the pre-1950s, when machines were utilized chiefly for increasing production output. The breakdown maintenance is the first and simplest upkeep, and consists of the repair of the machine when the equipment has already deteriorated in performance or broken down. There are two types of machine breakdown: function-loss and function-reduction. The first happens when all equipment stops functioning resulting in production losses, while the second refers to the deterioration of machines, causing other losses (such as minor stoppages, reduced speed, long set-up time, increased defects and longer cycle times), even if the equipment can still operate. The repairs are performed only when there is the lowest impact on operations[19] and no money is spent on maintenance until a machine fails to operate. The main weaknesses of this approach are high spare parts inventory costs, high machine downtime, low production availability, possibility of secondary damage and high inventory labour costs (fig. 11). There are two different types of breakdown maintenance: planned and unplanned. The first is applied when is more feasible to deal with the problem after it has already appeared, otherwise it is better to implement the unplanned system, but this can interfere with the production system. The breakdown maintenance is efficient only if employees detect abnormalities when they perform their daily checks or routinely monitor their equipment. A typical planned breakdown maintenance consists of the following steps:

- Evaluate the current machine and its condition.
- Restore the deteriorated equipment and correct the weaknesses.
- Make an information management system.
- Make a periodic maintenance system.
- Make a predictive maintenance system.
- Evaluate the planned maintenance system.

[19] Only the factories, which have a high level of flexibility, can easily adopt a preventive maintenance. Lean approach is in line with flexibility.

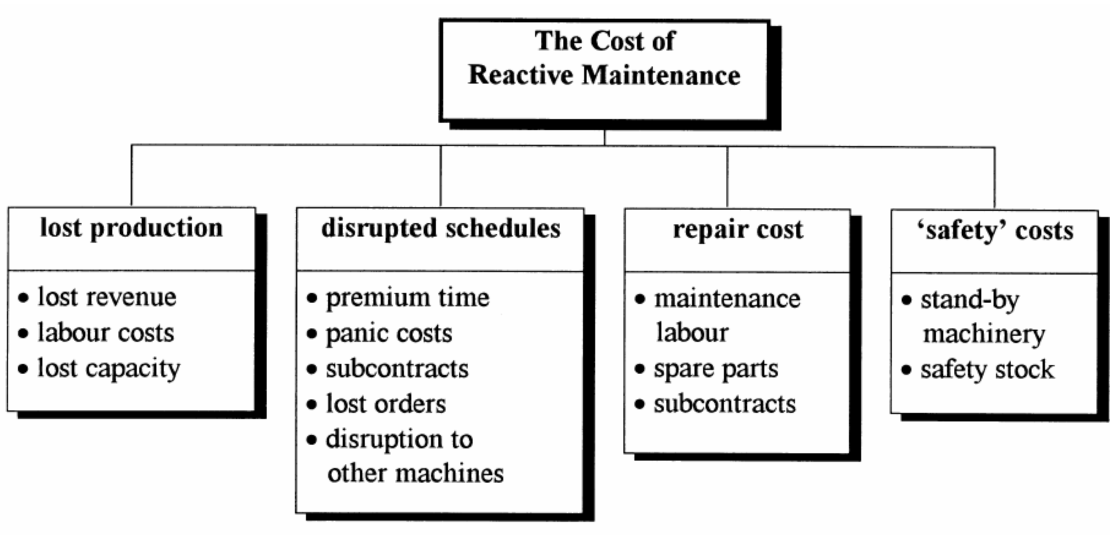


Figure 11: The real cost of reactive maintenance (Chand G., Shirvani B., 2000)

Preventive maintenance

Preventive maintenance is the first scientific approach applied to equipment management, it started in the 1950s, when plants became more complex and there was a push to mechanization. From that moment maintenance becomes an activity of the maintenance department ("I operate you fix"). Preventive maintenance is a time-based maintenance strictly related with "mean-time-to-failure" (MTTF) or "bathtub" curve for its characteristic shape (fig. 12). This curve, which is different for each machine, represents the probability of failure during time. Normally the probability of failure is quite high in the "start-up" phase (the first few weeks of practicality) due to installation problems. After this phase, the probability of failure is low for a quite long period called "normal life" period, and then it returns high due to equipment obsolescence ("equipment worn out").

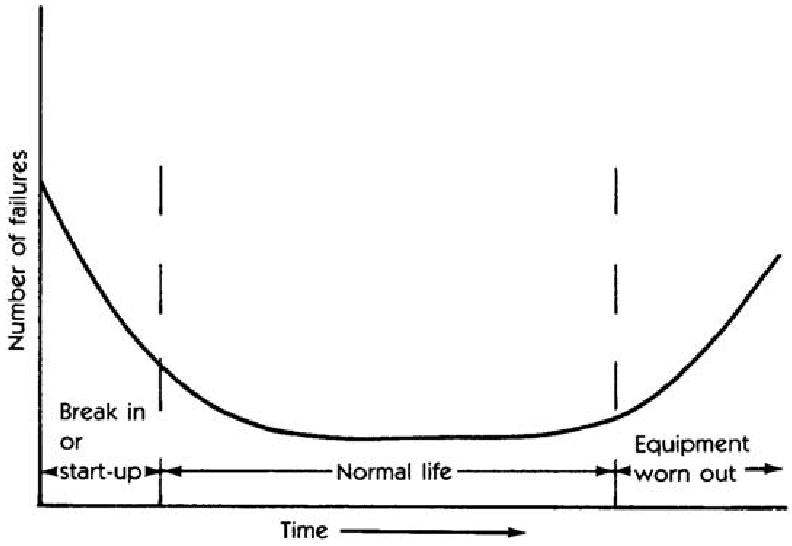


Figure 12: Typical bathtub curve (Mobley K. R. 2002)

The preventive maintenance is composed of a daily upkeep, consisting of standard operations of cleaning, checking, lubricating, tightening to prevent equipment from breaking down and deteriorating; periodic inspections of equipment components strictly related to the bathtub curve and past experiences of machine breakdowns; and restoration of deteriorated equipment. The advantages of this approach are the diminished probability of equipment breakdowns and extension of machines' life; on the other hand, it is necessary to stop the production at scheduled intervals to integrate the work. This model is permeated by uncertainty because the maintenance department is unable to predict the exact time for replacing or repairing the machine.

Predictive maintenance

Predictive maintenance consists of regular monitoring of the actual mechanical conditions, operating efficiency, and other indicators that provide the data required to ensure the maximum interval between repairs and minimize the number and cost of unscheduled failures. The main goals of predictive maintenance are improving productivity, overall effectiveness of manufacturing and production plants, and product quality. To achieve these objectives employees use some cost-effective tools like vibration monitoring, thermography, process parameter monitoring, tribology[20] and visual inspection to understand the current

[20] Tribology is the study of science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wear.

situation of each machine. Compared to periodic maintenance, predictive maintenance is condition-based upkeep. The adoption of predictive maintenance follows three main reasons:

1. As a maintenance management tool – This maintenance management can be considered an optimization tool for unnecessary downtime, scheduled or not; unnecessary corrective and preventive maintenance tasks; the expansion of the useful life of equipment; and the reduction of total life-cycle system.
2. As a plant optimization tool – The technologies used during the maintenance program are also used for establishing the best production practices for each equipment within the plant.
3. As a reliability improvement tool – The use of technologies are fundamental for detecting little deviations from normal operating parameters. As a reaction, maintenance organization has to plan minor adjustments to prevent breakdowns.

Corrective maintenance

The corrective maintenance is an upkeep task to identify, isolate and rectify a fault so that the machine can be restored at its intended performant level. Any equipment with design weaknesses must be redesigned. The process behind redesign is the DMADV (Define-Measure-Analyse-Design-Verify) approach, which differs from DMAIC, whose is more oriented to process improvement. Design stands for the designing of new processes required, including the implementation. Verify stands for the results being verified and the performance of the design to be maintained. This type of upkeep can be divided into immediate and deferred. In the first case, maintenance begins immediately after the failure, while the second upkeep follows a set of rules before the intervention.

Maintenance prevention

This type of maintenance consists of the design of a new equipment, after having understood the weaknesses of current machines. A new design will help in term of reliability and of the equipment’s maintenance. However, it is a complex process that can be subdivided into four main components: Design, fabrication, Installation and testing, and commissioning. With maintenance prevention (MP), machines have to be safe and easy to use; these qualities can be achieved after a deep analysis of equipment's weaknesses. The ultimate goal of MP is to remove completely the need for maintenance by designing robust machines that will not fail during their entire life cycle. MP adopts different tactics for reducing maintenance efforts. First of all the new designed equipment brings to a reduced frequency of maintenance, which means less scheduled downtime and lower maintenance costs. Secondly, there is a reduction of maintenance steps, which have a high impact on time and labour costs. Another tactic is the creation of an easy access for repair, so maintenance is faster and safer. A customized machine needs fewer parts for maintenance, so a saving in spare costs. Fifthly, the machine has to be composed of commonly available components, which permit to be quicker and avoids the use of custom-made parts. Finally, in many cases firms uses standardized components to be faster during the repair. The application of these tactics is important because that means that the company is taking consideration of maintenance into the design phase of equipment. Looking at the bathtub curve (see Preventive maintenance) the start-up phase is the most critical phase for failures, this gives the importance of the role of design for achieving immediately a high reliability level. If at the starting point this level is low, operators stop performing their regular housekeeping and preventive maintenance duties.

2.4 Total Productive Maintenance

Total Productive Maintenance (TPM) is a revolutionary approach for the management of machinery, it was developed in 1971 and consists of 5S, as a foundation, and eight supporting activities (sometimes referred to as pillars) (fig. 14). TPM is a logical, structured method of monitoring, inspecting, cleaning and evaluating the present and future equipment by using the resources that are available as effectively as possible. The goal of TPM is achieving a result of zero defects, zero accidents, and zero breakdowns[21] by a maximization of equipment effectiveness, the involvement of every single employee, the creation of a thorough system of preventive maintenance and its promotion through motivation management. The term "Total" has three different meanings:

- Total effectiveness of machines to improve profitability,

[21] Originally, the number of accidents was not considered as a goal to achieve, this means that over time the theme of safety has become important, becoming also a pillar of TPM.

- Total upkeep achieved applying maintenance prevention and maintainability improvement,
- Total participation of employees from top management to workers applying autonomous maintenance adopting small group activities.

At the basement of TPM, there are the 5S, whose goal is to create a clean and well-organized work environment using visual means to achieve consistent operative results. This lean method encourages maintenance team members to improve their working conditions and helps them to reduce waste and unplanned downtime. The basement is composed of:

- Sort (*Seiri*) – Eliminate what is not needed and keep what is needed. Items that cannot be removed immediately should be tagged for subsequent removal.
- Straighten (*Seiton*) – Position things in such a way that they can be easily reached whenever they are needed. Straightening aids efficiency; items can be found more quickly and employees travel shorter distances. Items that are used together should be kept together.
- Shine (*Seiso*) – Keep things clean and tidy; no refuse or dirt in the work area. Cleaning is considered an inspection process because it is easier to identify some abnormalities and pre-failure conditions. Cleaning should become an integrated part of the daily routine.
- Standardize (*Seiketsu*) – Maintain cleanliness and order – create standards for performing the above three activities. Scheduling requires checklists and schedules to maintain and improve neatness. This step includes also prevention from the accumulation of unneeded items, wrong procedures and from damages to equipment and materials.
- Sustain (*Shitsuke*) – Develop a commitment and pride in keeping to standards. Training is the key to sustaining the effort and involvement of all parties. Sustain entails making a habit of properly maintaining standard procedures and periodic cleaning schedules, introduced as part of the standardize phase. This is the most difficult stage to implement because there is a tendency to return to the old status quo. Therefore, the organization has to be focused on new habits and a new standard of workplace organization.

After having implemented all these steps, the organization has to maintain a constant control over time. It is recommended to make weekly audits at the very beginning and monthly ones once the system is stabilized. The audit is necessary for validating the accountability of 5S plans and targets. The 5S audit is a planned, independent, documented appraisal supported with graphs and evidence to determine if 5S procedures and guidelines are being met. First of all the audit is a review to control if the plans are being followed and if the results achieved are which are being targeted. In addition, audits are important tools for improvement because the auditor looks for a way to enhance 5S routines and discuss possible shortcomings.

Recently a sixth S has been added to the list: safety. This new approach looks at unsafe conditions and tries to set procedures to increase safety of equipment. Safety starts with a "job safety analysis" (JSA)[22], some training courses for employees and a good planning for work environment.

The eight pillars of TPM are mostly focused on proactive and preventative techniques for improving equipment reliability, and they are:

- Health & Safety – The objective of each firm is to achieve a goal of zero accident, zero health damages and zero fires, which can be achieved by a continuous cleaning of machine and a formalization of safe working procedures.
- Education & Training – Training is fundamental to make TPM work, workers have to be multi-skilled and with a high morale to achieve a zero losses result. Each operator has to be instructed in what they need to work safely in their designated operative centre. Training is a complex process that consists of:
    - An introduction of TPM.
    - Leadership training for the team leader and team manager.
    - Team-building skills for the whole team.
    - How to carry out training: train the trainer.
    - How to run and participate in meetings.
    - Root-cause analysis for faults.
    - The "office" software that is used in the organization.
    - General equipment safety and risk assessment procedures.
- Autonomous Maintenance (AM or *Jishu Hozen*) – Empowers and develops operators to be able to take care of small maintenance tasks. Employees will achieve a level of skills that allow them to carry out the basic maintenance of their own equipment. That makes them more responsible for the operations, recognizing abnormalities that

[22] A job safety analysis (JSA) is a procedure, which helps integrate accepted safety and health principles and practices into a particular task or job operation. In a JSA, each basic step of the job is to identify potential hazards and to recommend the safest way to do the job.

are developing. AM tasks are very quickly and can be done on a daily basis without any difficulty. Nakajima studied seven tasks for AM (Nakajima S., 1988):

- initial cleaning and restoration of the equipment,
- countermeasures at the source of the problems,
- cleaning and lubrication standards,
- overall inspection,
- autonomous standards,
- organization and tidiness,
- full autonomous maintenance.

AM imagines the creation of teams that have the responsibility of managing the equipment time with production and coordinating with the technicians. The main responsibilities of AM teams are (Borris S., 2006):

- Scheduling routine meeting, inspect routines and clean with the technical support and production personnel.
- Maintaining the minor stops system.
- Analysing the data.
- Creating the graphs, diagrams, and updating the activity board.
- Ensuring that the technicians/engineers are in a position to allocate time to resolving tasks.

- Planned Maintenance (PM) – The objectives of PM are understanding the problems of the equipment and adopting the right solutions to avoid in future. A routine maintenance has the goal of preventing breakdowns, improving reliability and maintainability by 50%, and reducing upkeep costs by 20%, thanks to the institution of cross-functional teams (also called Zero Fails teams) composed of operators, equipment engineers, production engineers, managers and technicians. This heterogeneity is fundamental for understanding each other's priorities and how costs, safety, technical issues and production problems affect each member. PM teams have to resolve all the equipment failures, quality issues and throughput. The remedial action follows a standard, which have to be improved over time. The first important activity is the research of a root-cause solution for the failure. After its achievement, teams realize a draft of the PM procedures. The solution must be verified with the PDCA tool, and if it gives a positive response, the countermeasure can be transformed into the final procedure that will be used for training. PM teams main responsibilities are (Borris, 2006):

- Analyse root-cause solutions.
- Redesigns to overcome failure prone components.
- Establishing the standards for the toolset.
- Creating procedures and risk assessments.
- Establishing and optimizing a PM interval or method of self-diagnosis.
- Clean and inspect routines.
- Technical support for the AM side of the teams and attendance at the Zero Fails meetings.
- Maintaining a PM section on the activity board.
- Monitoring the progress of the PM team.

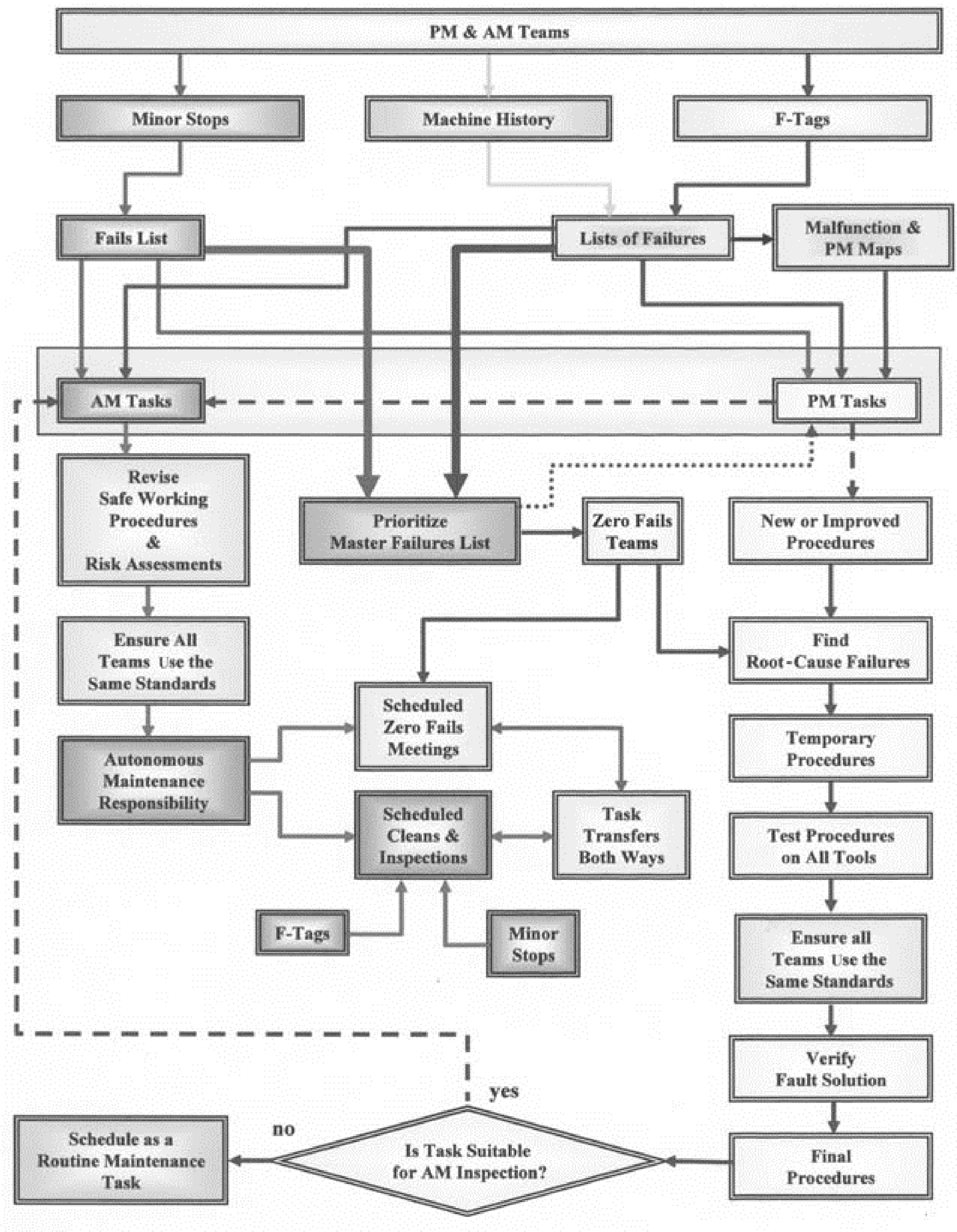


Figure 13: AM and PM team activities (Borris S., 2006)

- Quality Maintenance – A constant analysis of product quality variation, analysis of the causes and successively the implementation of a change or upgrade of the process. The main target is the reduction of in-process defects by 50% and quality costs by 50%. The company has to collect data about in-house and customer defects to understand the main criticalities within the process.

- Focused Improvement (*Kobetsu Kaizen*) – Consists of applying the *kaizen* methodology to achieve zero defects and elimination of downtime. It consist of analysing technical breakdown and creating countermeasures against major production losses.
- Office TPM – The creation of an office that supports and improves productivity, efficiency, and flow in the administrative functions while identifying losses.
- Early Equipment Management – This pillar have three main categories: equipment development planning, maintenance prevention design and life cycle costing. This type of management consists of directing practical knowledge for the improvement of the new equipment design.

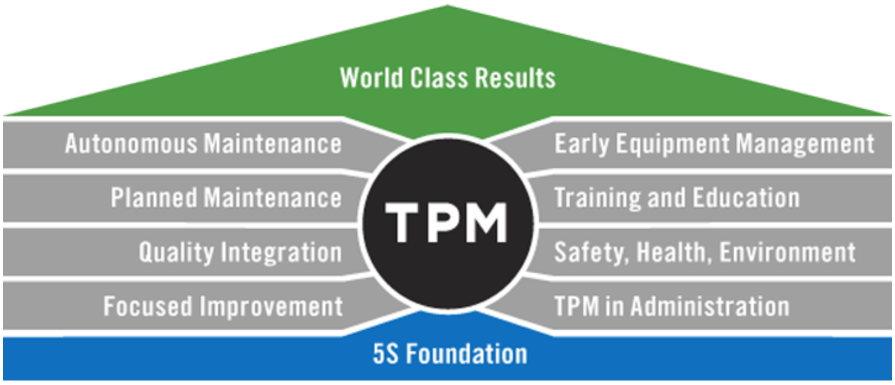


Figure 14: The traditional TPM model (leanproduction.com)

2.5 TPM Benefits

TPM is usually divided into short term and long-term elements. In the short term, the focus is the autonomous maintenance program for the production department, and skill development for operations and maintenance personnel. In the long term, instead, the efforts are focused mainly on new equipment design and elimination of sources of equipment time losses. The implementation of this system brings some organizational benefits like well-defined areas of responsibility, because each individual is responsible for the maintenance of a machine line, and a direct contact between the operators and the maintenance technicians. In technical terms, the production improvement is given by a wide increase in the equipment availability, frequently the largest of three losses in Overall Equipment

Efficiency (OEE) metric. It is extremely important to measure OEE in order to expose and quantify productivity losses, and to measure and track improvements resulting from TPM initiatives. One of the early goals of TPM is to restore machinery to its basic condition. TPM reduces all the sixteen major losses:

Losses that impede equipment efficiency:

1. Shutdown loss
2. Setup and adjustment loss
3. Cutting tool replacement loss
4. Start-up loss
5. Minor stops and idling
6. Speed loss
7. Quality defect and rework loss
8. Breakdown loss

Losses that impede human work efficiency:

9. Management loss
10. Motion loss
11. Line organization loss
12. Internal logistics loss
13. Measurement and logistic loss

Losses that impede effective use of production resources:

14. Yield loss
15. Energy loss
16. Consumable loss (e.g. tools)

OEE measurement is a key performance indicator (KPI) in conjunction with lean manufacturing efforts to provide an index of success. The formula for equipment effectiveness must look at the availability, the rate of performance, and the quality rate. The formula could be expressed as:

$$Availability \times Performance\ rate \times Quality\ rate = OEE$$

The availability rate represents the percentage of scheduled time that the operation is available to operate. The formula is:

$$\frac{Loading\ time - Downtime^{23}}{Loading\ time} \times 100 = Availability$$

The performance rate is the speed at which the machine runs as a percentage of its designed speed.

$$\frac{Total\ operating\ time - Speed\ losses^{24}}{Total\ Operating\ time} \times 100 = Performance$$

The quality rate represents the good units produced as a percentage of the total unit started. The formula for calculating Quality is:

$$\frac{Net\ operating\ time - Quality\ losses^{25}}{Net\ operating\ time} \times 100 = Quality$$

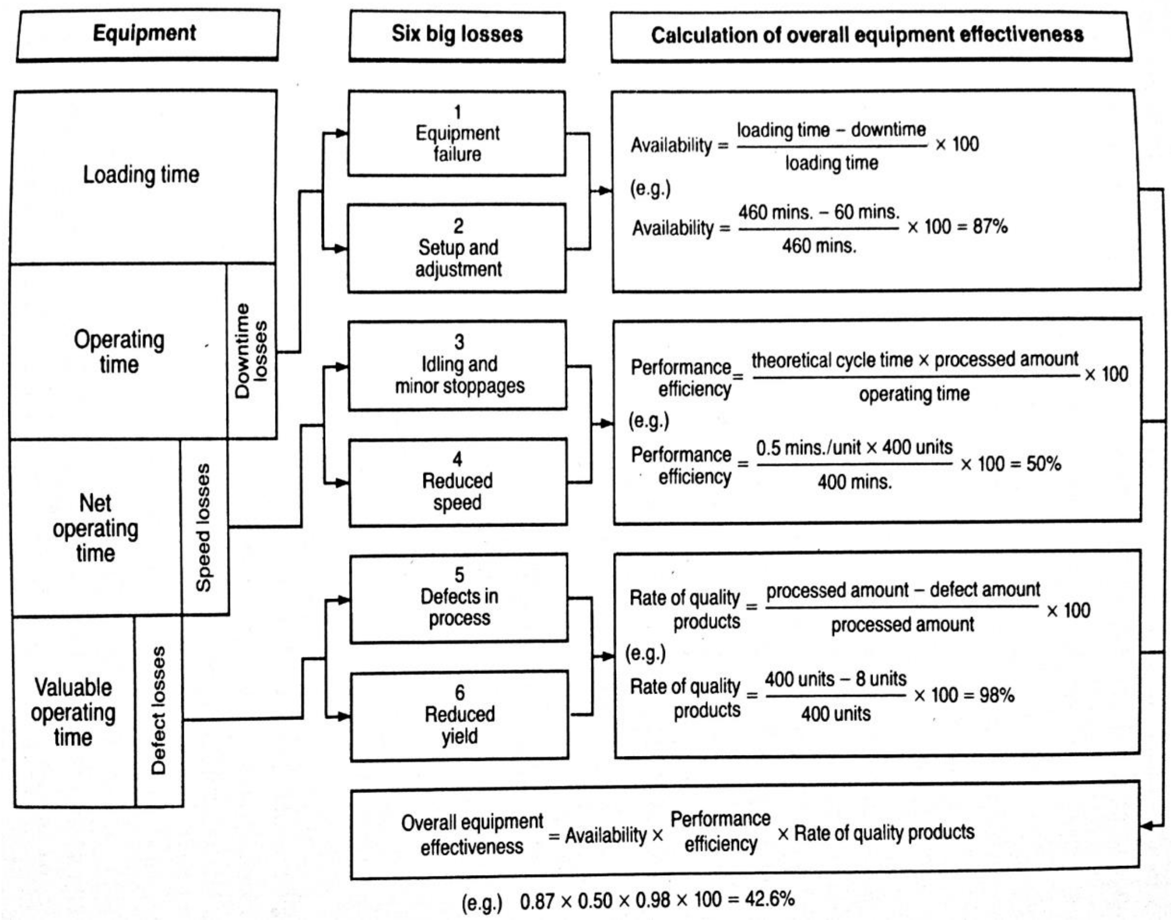


Figure 15: Overall Equipment Effectiveness and Goals (Nakajima S., 1988)

[23] Equipment downtime involves equipment stoppage losses resulting from failures, setup procedures, exchange of dies etc.

[24] Speed losses are considered when the machine is idling, and when minor stoppages occur.

[25] Quality losses are evaluated when there are defects in process and a reduction in yield.

From the OEE it is possible to achieve another measure, the TEEP (Total Effective Equipment Performance). TEEP measures effectiveness against calendar hours, that is, 24 hours per day, 365 days per year. The calculation formula for the TEEP is:

$$TEEP = Loading \times OEE$$

2.5.1 Others maintenance performance indicators

Indicators are fundamental to have a perspective on company's goals, specific objectives and business strategies. The problem of indicators is that they look at the past, so maintenance managers have not to put them too much in consideration. Anyway, they are useful for understanding the direction the firm is following, and operatively they reveal problems, measure performances and drive for improvements. Performance indicators related to maintenance management can be classified into three categories: equipment, process and cost performance indicators.

Equipment performance indicators

Equipment performance indicators reveal equipment issues, so the status of the machines. For measuring equipment performance there are some key areas to analyse, in particular safety, availability, reliability, maintainability and utilization.

Safety Indicators

These indicators monitor injuries and environmental damages caused by equipment failures.

- *Number of potential safety incidents associated with a particular type of equipment.*
- *Number of environmental incidents associated with a type of equipment.*
- *Number of first-aid cases associated with a type of equipment.*
- *Number of lost-day cases associated with a type of equipment.*
- *Number of fatality cases associated with a type of equipment.*

Availability indicators

Availability, as explained in TPM benefits, is a component for measuring the Overall Equipment Efficiency.

- $Weekly\ total\ availability = \frac{Equipment\ uptime}{168}\%$
- $Weekly\ operational\ availability = \frac{Equipment\ uptime}{Operations\ time}\%$
- $Weekly\ manufacturing\ availability = \frac{Equipment\ uptime}{Manufacturing\ time}\%$
- $Weekly\ dependent\ availability = \frac{Equipment\ uptime}{Equipment\ time}\%$
- $Supplier\ dependent\ availability = \frac{Equipment\ uptime}{Supplier\ equipment\ time}\%$
- *Availability breakdowns:* $Downtime\ \% = 1 - Availability$

Reliability indicators

These indicators measure how often the equipment fails.

- *Mean time between failures:* $Week\ MTBF = \frac{Equipment\ uptime\ in\ 4\ weeks}{\#\ of\ failures\ in\ 4\ weeks}$
- *Productive MTBF:* $Week\ MTBF = \frac{Productive\ time\ in\ 4\ weeks}{\#\ of\ failures\ withi\ 4\ weeks'\ Productive\ time}$
- *Mean units between failure:* $Weekly\ MUBF = \frac{Total\ \#\ of\ production\ units\ processed}{\#\ of\ failures\ in\ the\ week}$
- *Mean cycles between failures:* $Weekly\ MCBF = \frac{Total\ \#of\ equipment\ cycles}{\#\ of\ failures\ in\ the\ week}$
- *Mean time between assists:* $Weekly\ MTBA = \frac{Productive\ time\ in\ 4\ weeks}{\#\ of\ assists\ in\ 4\ weeks}$

Maintainability indicators

Maintainability expresses how quickly the equipment can be assisted or repaired.

- *Mean time to repair:* $Week\ MTTR = \frac{Total\ repair\ time\ in\ 4\ weeks}{\#\ of\ failures\ in\ 4\ weeks}$
- *Mean time to assist:* $Week\ MTTA = \frac{Total\ assist\ time\ in\ 4\ weeks}{\#\ of\ assists\ in\ 4\ weeks}$
- *Mean time off line:* $Week\ MTOL = \frac{Total\ equipment\ downtime}{\#\ of\ down\ events}$
- *Repair breakdown*

Utilization indicators

These indicators measure the usage of the machines.

- $Weekly\ total\ utilization = \frac{Productive\ time}{168}\%$
- $Weekly\ total\ utilization = \frac{Productive\ time}{Operations\ time}\%$

Process Performance indicators

Process performance indicators explain how well maintenance management operates. Some processing issues influence machines performance. Performance indicators are labour productivity, non-productive downtime, customer satisfaction, and operational misses.

Labour productivity indicators

Labour productivity is the measurement of employees' productivity in the maintenance operations.

- $Headcount\ ratio = \frac{Total\ equipment\ count}{Total\ headcount}$
- $Work\ order\ ratio\ = \frac{Total\ work\ count}{Direct\ support\ headcount}$
- $Downtime\ ratio = \frac{Total\ downtime}{Direct\ support\ headcount}$
- Work order per shift: $Work\ order = \frac{\#\ work\ orders\ worked\ by\ the\ give\ shift}{Headcount\ of\ the\ shift}$

Non-productive downtime indicators

These indicators shows non-value added wait times during unscheduled and scheduled downtime.

- *Response time*
- *Waiting for part time*
- *Waiting for support*

Customer satisfaction ratio

Customer satisfaction is measured analysing how maintenance organization serves internal customers.

- *Regular customer service ratings*
- *Real-time feedback after each work order*
- $Customer\ \frac{request}{complaint} = \frac{\#\ of\ customer\ requests}{\#\ of\ customer\ complaints}$

Operational Misses and Error Rates

These rates measure the number of misses and errors made by the maintenance organization.

- $SWAT^{26}\ rate = \frac{\#\ of\ SWATs}{Total\ \#\ of\ down\ incidents}$
- $Escalation\ rate = \frac{\#\ of\ escalations}{Total\ \#\ of\ down\ incidents}$
- $Spare\ outage\ rate = \frac{\#\ of\ spare\ out\ of\ stock}{Total\ \#\ of\ spare\ requested}$
- $PM\ miss\ rate = \frac{\#\ of\ PM\ misses}{Total\ \#\ PM\ performed}$

Cost performance indicators

These indicators reveal the expense dedicated to maintenance activities.

- $Cost\ per\ equipment = \frac{Total\ maintenance\ cost\ of\ equipment}{\#\ of\ equipment}$
- $Cost\ per\ repair = \frac{Total\ repair\ cost}{\#\ of\ repairs}$

2.6 The Three stages of TPM Development

The implementation of TPM is a complex process composed of twelve steps that can be aggregated in three macro-stages: preparatory, implementation and stabilization stage. To make all these phases work the company has to focus on three fundamental conditions for improvement:

[26] SWAT is an equipment hard-down situation for which a task force is required to identify the root cause and solve the issues.

- Motivation (*yaruki*) of workers;
- Competences (*yaruude*) obtained with an educational campaign.
- Work environment (y*aruba)* that has to support the implementation of TPM without any risk of coming back to the *status quo*.

2.6.1 The preparation stage

Step 1: Announce top management's decision to introduce TPM

This step consists of communicating the implementation of TPM to the entire organization. It is essential to raise awareness through multiple avenues so employees have a proper understanding of TPM and that creates a prolific work environment for TPM. Top management has a critical role in this phase because it first has to believe in the project and then has to explain the concepts, goals and expected benefits of TPM. It is essential to communicate the change to the entire organization because this system is total, so it depends on the participation of everybody, from top management to front line workers. Employees are informed about the change through the in house magazine displayed on the notice board, while customers and suppliers through a letter.

TPM requires that management have to coach employees to deal with the equipment on their own by enhancing their skills and promoting autonomous maintenance. On the other side, workers must commit themselves becoming able to handle and maintain the equipment. These results can be achieved only with the creation of a favourable environment and a change in people's attitudes and habits.

Step 2: Launch educational campaign

The second step consists of the development of training and a promotional program that has to start immediately after the introduction of the plan. The purpose is to raise morale and soften resistance to change. The best way to build a strong motivation for change is creating a controlled crisis showing the improvements that the company can achieve with the new approach. A high readiness to change can be achieved only if each worker perceive a low personal risk from change and a high dissatisfaction with current situation. If these two variables are not managed correctly, there is the risk of coming back to the *status quo*. Many employees consider TPM activities as additional work, and show no openness or willingness to learn. They are reluctant to change because they do not see the benefits of TPM and the reason for modifying their normal practices.

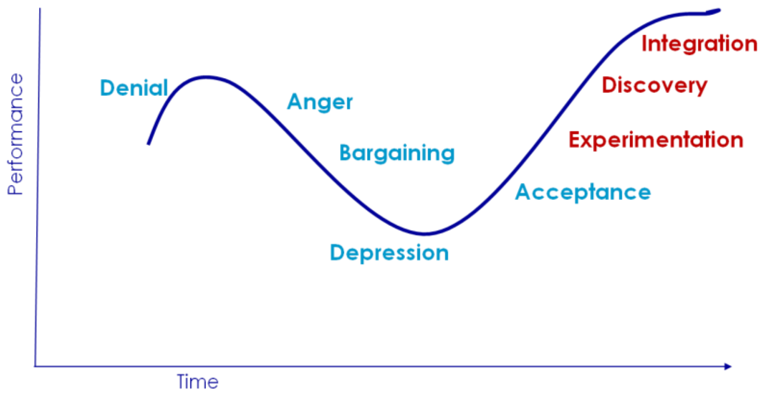


Figure 16: Individual change curve (sacredstructures.org/movement/change-curve-bother-understand)

Usually workers are trained using presentations or other visual materials during meetings, with the presence of supervisors and other managers. Sometimes the lessons are presided over external consultants employed by the firm, which have not experience enough on TPM principles. During this stage, the company has to organize a promotional campaign using banners, placards, signs, flags bearing TPM slogan to promote enthusiasm that creates a positive environment.

Step 3: Create organizations to promote TPM

During the third step the company has to build a promotional structure (also called TPM office) based on an organizational matrix, composed of horizontal committees and project teams at each level of the organization. These small groups are very heterogeneous, that characteristic gives a diversity of views represented, high performance, and a variety of resources shared. In addition, small groups have the advantages of regular interactions, easiness of sharing information, recognition of individual contributions to groups, strong group identification and higher group satisfaction. The main activities managed by the TPM office are:

- Attendance with top management to training lessons.
- Attendance to the preparation of the master plan.

- Create a budget considering resources, equipment, staff and all the costs needed for the plan.
- Negotiation with corporation about new maintenance activities that employees have to perform.
- Specify benchmarks and ratios to measure the progress of implementation.
- Creation of the introductory campaign about TPM to apply in the first step.
- Cooperation with top management throughout the entire implementation phase.

Step 4: Establish basic TPM policies and goals

At the fourth step, the company has to establish basic policies and goals. Goals should be specific, realistic, attainable, measureable, and time related. Key performance indicators (KPIs) are the best measure for sustaining results once the approach is implemented. The company has to set medium-to-long term goals, which have to be measured in each department at each level. Medium term objectives are necessary to understand the degree of success of the implementation and to measure the gap between desired outcome and results achieved. Shorter-term results are necessary for improving motivation among workers, indeed the company has to celebrate it to create a positive work environment. Instead, policies are abstract written or verbal statements.

Step 5: Formulate a master plan for TPM development

Finally, the TPM promotional headquarters have to establish a master plan for TPM implementation. This plan consists of a daily schedule of operations with all the steps of the preparation stage inserted. Many firms consider a preparatory stage, called step 0, which consists of cleaning and reorganizing the *gemba* for improving OEE through the elimination of the six big losses.

2.6.2 The implementation stage

Step 6: Hold TPM "Kick-off"

The first step of the introduction stage is the TPM "kick-off" and consists of the implementation of TPM's standards into daily routine. Individual workers play a crucial role in this stage because they are responsible for the accomplishments of the goals established. The six big equipment losses are the main objectives of this phase, each employee has to eliminate these losses adopting TPM policies. Sometimes managers organize some shop floor meetings to improve workers' morale and dedication. At these encounters, clients and affiliates are also invited, and the top management illustrates the key phases of the preparatory stage and celebrates the results achieved.

Step 7: Improve equipment effectiveness

The implementation of TPM activities can be assembled as follows (Nakajima S., 1988):

- Maintaining well-regulated basic conditions (cleaning, lubricating, and bolting).
- Adhering to proper operating procedures.
- Restoring deterioration.
- Improving weaknesses in design.
- Improving operation and maintenance skills.

Small group members engineer these countermeasures to breakdowns. This phase is critical because some workers, who doubt goals can be achieved easily, are reluctant to the application of TPM. During the overhaul, to each project team is assigned a piece of equipment to be managed according to TPM principles for improving workers confidence. This method is very effective because proves the benefits of TPM and gives maintenance experience to workers. During this stage, many techniques are applied to promote improvements. In particular, the PM analysis is commonly used because it is more than an improvement methodology; it is a different way of thinking about problems and the context in which they occur (Shirose K., et al., 2012). PM analysis is a modification of the conventional improvement approach, used for example in QC model, which consists of eight steps:

1. Evaluate current loss picture and select a project theme;
2. Set improvement targets;
3. Understand the current situation;
4. Conduct factor (cause-and-effect) analysis;
5. Identify and implement countermeasures;

6. Evaluate results and make required adjustments;

7. Institute standards and procedures to prevent recurrence;

8. Re-evaluate Loss picture and plan for the next project(s).

"P" stands for "physical" because it is an analysis to understand the physical principles behind an abnormal event or for "phenomenon" as a study of deviations from normal to abnormal state. "M" stands for "mechanism" and for the four production inputs (4Ms): machine, material, method and man. P-M analysis physically analyses chronic losses according to the inherent principles and natural laws that govern them. This analysis clarifies the mechanics of their occurrence and the conditions that must be controlled to prevent them (Shirose K. et al., 2012). PM consists of eight steps analysed in the table below (Table 1).

Table 1: Steps in P-M analysis (Shirose K., et al., 2012)

Clarify the phenomenon	Carefully define and categorize the abnormal occurrence
Conduct a physical analysis	Describe the phenomenon in physical terms, e.g., how the parts or process conditions change in relation to each other to produce the defect or failure
Define the phenomenon's constituent conditions	Identify all the conditions that will consistently produce the phenomenon
Study production input correlations (4Ms)	Look for potential cause-and-effect relations between the constituent conditions and equipment (machine, jigs, and tools) materials, work methods, and human factors
Set optimal conditions (standard values)	Review the equipment's current precision levels to determine where new or revised standards are deficient
Survey causal factors for abnormalities	Using appropriate measuring methods, confirm which factors identified in steps 3 and 4 exhibit deviating conditions
Determine abnormalities to be addressed	Review survey results and list all abnormalities (including slight defects) to be addressed

Propose and make improvements	Implement a corrective measure or improvement for each abnormality, then institute operating standards and preventive maintenance procedures to maintain optimal conditions

Step 8: Establish an autonomous maintenance program for operators

Autonomous maintenance (AM), one of the eight pillars, has to be implemented after the kick-off. AM consists of a training course necessary to perform a correct maintenance which operators have to adopt to their own equipment. The activities are inspection, lubrication, and cleaning and they have to become part of the operators' routine. The formalization of the 5S's is essential before starting to adopt the AM program, which is very complex and consists of seven steps (Table 2):

Initial cleaning	Clean to eliminate dust and dirt mainly on the body of the equipment; lubricate and tighten; discover problems and correct them
Countermeasures for the causes and effects of dirt and dust	Prevent cause of dust, dirt and scattering; improve parts that are hard to clean and lubricate; reduce time required for cleaning and lubricating
Cleaning and lubricating standards	Establish standards that reduce time spent cleaning, lubricating, and tightening (specify daily and periodic tasks)
General inspection	Introduction follows the inspection manual; circle members discover and correct minor equipment defects
Autonomous inspection	Develop and use autonomous inspection check sheet
Organization and tidiness	Standardize individual workplace control categories; thoroughly systemize maintenance control • Inspection standards for cleaning and lubricating • Cleaning and lubricating standards in the workplace • Standards for recording data • Standards for parts and tools maintenance
Full implementation of autonomous maintenance	Develop company policy and goals further; increase regularity of improvement activities Record MTBF analysis results and design countermeasures

Table 2: Seven steps for developing Autonomous maintenance (Nakajima S., 1988)

Step 9: Set up a scheduled maintenance program for the maintenance department

After the implementation of autonomous upkeep, the firm has to create a scheduled maintenance program for the maintenance department. These two types of maintenance activities has to be coordinated. Initially the implementation requires more time, because many activities have to be completed. During this phase employees has to identify problems and weaknesses of machines, and study countermeasures. Usually firms adopt overtime or subcontracting to face the work excess. Nevertheless, the volume of maintenance work will diminish gradually, as soon as the maintenance activities become part of the operator's routine. Consequently, the number of malfunctions will diminish like maintenance activities.

Step 10: Conduct training to improve operations and maintenance skills

The tenth step is entirely dedicated to investments in people competences and skills adopting training, therefore, employees can manage their equipment properly. There are different types of training for different levels within the organization. Following a top-down approach there is a course for supervisors about design modification, another for experienced workers about applied techniques, for top and middle ranked workers about middle skills, and for low ranked and new workers for basic equipment operations. After the course, it is important to institutionalize some examinations for equipment maintenance to analyse training effectiveness.

Step 11: Develop early equipment management program

The last step of the implementation phase is the development of early equipment management. As already seen in the bathtub curve, the installation phase of new equipment registers a high level of failures due to design, fabrication and installation problems. To these start-up problems workers have to make many improvements before starting to operate at a normal pace. In this step the main activities are aimed at (Nakajima, 1988):

- Achieving the highest levels possible within the limits established at the equipment investment plan.
- Reducing the period from design to stable operation
- Processing through this period efficiently, with minimum labour and no workload imbalance.

- Ensuring that the equipment designed is at the highest levels of reliability, maintainability, economical operability, and safety.

Design engineers and maintenance staff have to cooperate to reduce at minimum problems at the source. An analysis of the life cycle cost (LCC) shows that the approximately the 75-95% of LCC derived from the design stage (Blanchard B. S., 1978) (fig. 17).

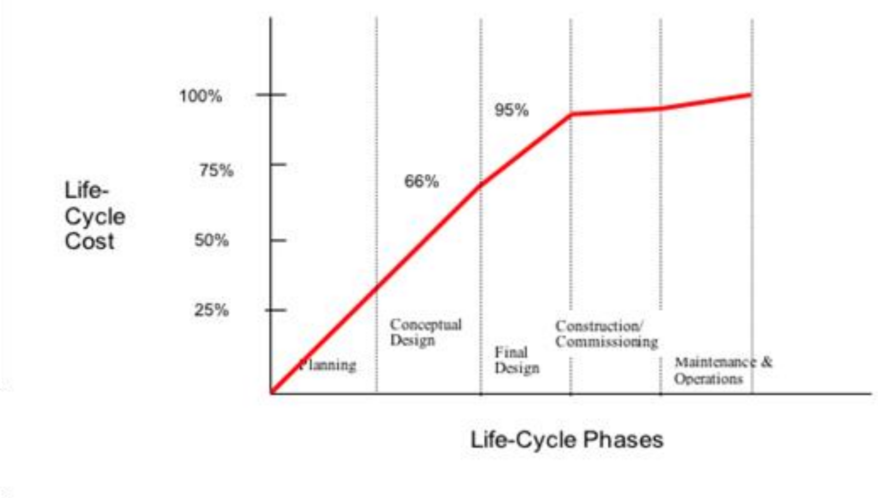


Figure 17: Stages of life cycle cost commitment (Blanchard B. S. 1978)

2.6.3 The stabilization stage

Step 12: Implement TPM fully and aim for higher goals

After the implementation step, the firm has to consolidate this new system adopted. During this period, the company celebrates the results achieved but also create new goals to pursue in future.

2.7 Problems in implementation

As already seen, the implementation process is not an easy task. It requires twelve steps to be completed, including also commitment, money, time, resources and manpower from all the stakeholders. During these phases, there are many barriers to overcome for a correct adoption of TPM. This system have a high impact on work culture and creates a radical restructuring of work (see influence of TPM on job characteristics). When there is a change there are always restraining forces that want to preserve the *status quo*. Impediments to change, normally, are expressed at three different levels: individual, group and organizational. At individual level, workers feel insecurity and fear to new solutions, they do not know how the change can affect them, in particular their status, habits, routine and salary. Absenteeism, turnover and inertia are typical signs of resistance to change. Groups, instead, are reluctant to change because they want to preserve their norms and the cohesiveness achieved during time. At the organization level a change creates a revolution in the culture of the firm and a conflict for power. Kotter (Kotter J., Schlesinger L., 2008), about the problem of the resistance for change, analysed different approaches to adopt in different situations. From a low to a high degree of conflict he suggests to adopt the following methods: education, participation, facilitation, negotiation, manipulation and coercion. Looking into details, many studies have analysed the barriers that a company faces during the implementation. Attri Rajesh (Attri Rajesh, Grover Sandeep, Dev Nikhil, 2014) in his study considers five groups of potential barrier: behavioural, human & cultural, technical, strategical and operational (Fig. 18).

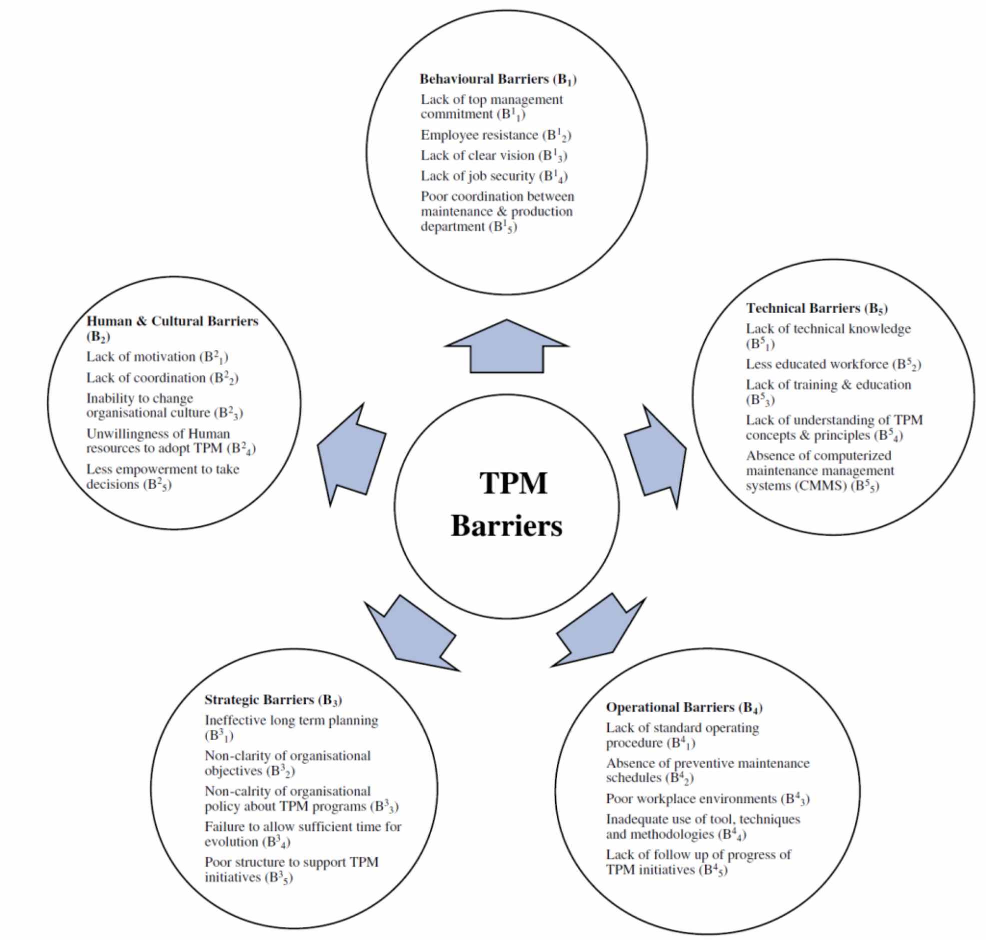


Figure 18: Barriers in the TPM implementation (Attri Rajesh, et al., 2014)

Behavioural barrier

Behavioural barriers are related to the behaviour of persons working within the organization. During the implementation, the role of top management is fundamental for the application of TPM, therefore, a lack of commitment and support jeopardize a correct application of the new approach. Top management has to coordinate a multi-level communication system to all the workers, explaining the benefits of TPM and linking it to the strategy and the objectives of the company. Employee resistance is another barrier, workers feel a sense of insecurity and apprehension of loss of specialization due to technological improvements and consider the implementation an unnecessary waste of money and time. To avoid this "inertia" the organization has to create a reward mechanism as an incentive. This reward system has to be linked to the targets and goals set for TPM implementation. Finally, a poor coordination between maintenance and production department is an operative problem that makes TPM difficult to applicate. The constitution of teams is essentially the solution for low integration and communication within departments.

Human and cultural barrier

These barrier are related to the culture that permeates the organization and affects values, behaviours and perceptions of employees. During the preparation phase it was highlighted the importance of the creation of a good climate to increase motivation and commitment for the change. In some cases firms are unable to change organisational culture properly, so workers prefer to return to the previous situation even if this represent a problem for the company. The top management has to recognize and support driving for change forces, adopting a problem solving process to plan, enforce and evaluate the change.

Strategic barrier

These barriers are related to the strategic decisions of the TPM implementation. These decisions need a long-term perspective that brings to success for the company. A short-term approach is not in line with the strategy of the firm, and it brings to a non-clarity of the organization objectives. For these reason firms have to institutionalize a complex system to support TPM initiatives.

Operational barrier

Operational barriers are strictly related to maintenance procedures. In particular, there are problems when there is a lack of standard operating procedures (SOP), poor workplace environment, inadequate use of lean tools, lack of preventive maintenance schedules, and lack of follow-up of the progress of TPM initiatives. Many times employees continue to "see" maintenance as bringing the equipment back on line as fast as possible instead of focusing on failure prevention.

Technical barrier

Technical barriers are connected with TPM pillars and consists of lack of training and education for employees and lack of awareness and understanding of benefits of TPM. The company, before the implementation of TPM, has to recognize skills and abilities that it wants its workers to have and then plan suitable training to develop these skills. The educational background of the employees seriously affects the speed of implementation.

2.8 The influence of TPM on job characteristics

The implementation of Total Productive Maintenance creates a radically change in employees' job characteristics (Nasurdin A. M., et al., 2005). Workers have to complete more maintenance task, so they have more responsibilities (job enrichment) within the overall organizational system. The job characteristic theory suggests five "core" job dimensions (skill variety, task identity, task significance, autonomy, and feedback) that affect five work related outcomes (satisfaction, performance, motivation, absenteeism, and turnover). TPM affects all these five dimensions differently. Looking in more detail:

- Skill variety – It refers to the necessity for employees to perform different activities to avoid alienation. To perform correctly these activities each employee has to use different talents and skills. With the adoption of TPM, workers have to learn additional skills for applying preventive maintenance techniques. Each employee is responsible for his equipment, so a TPM technician have more responsibilities than other standard workers have. In conclusion, the implementation of TPM has a positive impact on workers' skill variety.

- Task identity – It refers to the visibility of the job as a part of the "whole" project of the firm in terms of outcomes and results. The application of TPM considers the adoption of autonomous maintenance tasks. By applying these assignments workers, subsequently, complete identifiable piece of work from the start to the end. The continuous improvement of these activities, focused on enhancing machine operations, transforms the job into greater responsibilities and more task identity.
- Task significance – Significance reflects the role of the job in terms of the impact on the lives or works of the others, both in the organization or in the external environment. TPM creates a result of higher value at a lower cost, enhancing company profitability and customer benefits. In this sense, Total Production Management can be considered a booster of satisfaction both for the organization's workforce and for the environment.
- Autonomy – Autonomy is the characteristic of freedom, discretion and independence that the job lets to the individual in scheduling the work. TPM gives high level of discretion to employees in the decision making process and in the beginning of corrective actions to prevent any equipment failure. Each operator is involved in a small group, during which every member gives suggestions and ideas for improvements.
- Feedback – Feedback is the degree of responses the worker obtains about the effectiveness of his performance. By the fact that TPM is "total", all the departments are involved. For this reason, there are cross-functional teams, consisting of employees of different disciplines that have to interact and communicate each other to minimize production losses. This frequent exchange of information and the cooperation increase sharply the feedback dimension. In addition, workers use measurements like KPIs, OEE and other maintenance indicators as a feedback to adopt corrective actions to the machines.

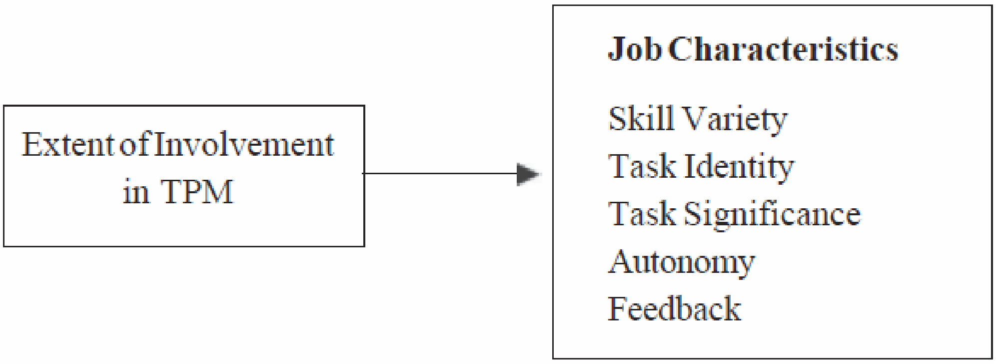


Figure 19: The impact of TPM on job characteristics (Nasurdin A. M., et al. 2005)

In conclusion, firms that adopt TPM, due to the impact on all of the five "core" job dimensions, have a better work environment in terms of performance, motivation and satisfaction. This reflects on lower levels of turnover and absenteeism.

2.9 Contextual elements

The procedures for using TPM to maximize efficiency and profitability must be tailored to the individual company. According to Wireman (1991), *"there is no single correct method for the implementation of a TPM programme".* Each firm has to develop its own roadmap, because of various needs and problems, depending on some contextual element like the type of industry, production method, and equipment type and condition. These contextual elements can be divided into three categories: environmental, organizational and managerial context. They affect widely the implementation of two main pillars of TPM: Autonomous and Planned maintenance. In the study proposed by McKone (McKone K. E:, et al., 1999), AM is composed of four elements: teams, housekeeping, cross training and operator involvement, while PM consists of three elements: Information tracking, disciplined planning and schedule complaining (Fig. 20).

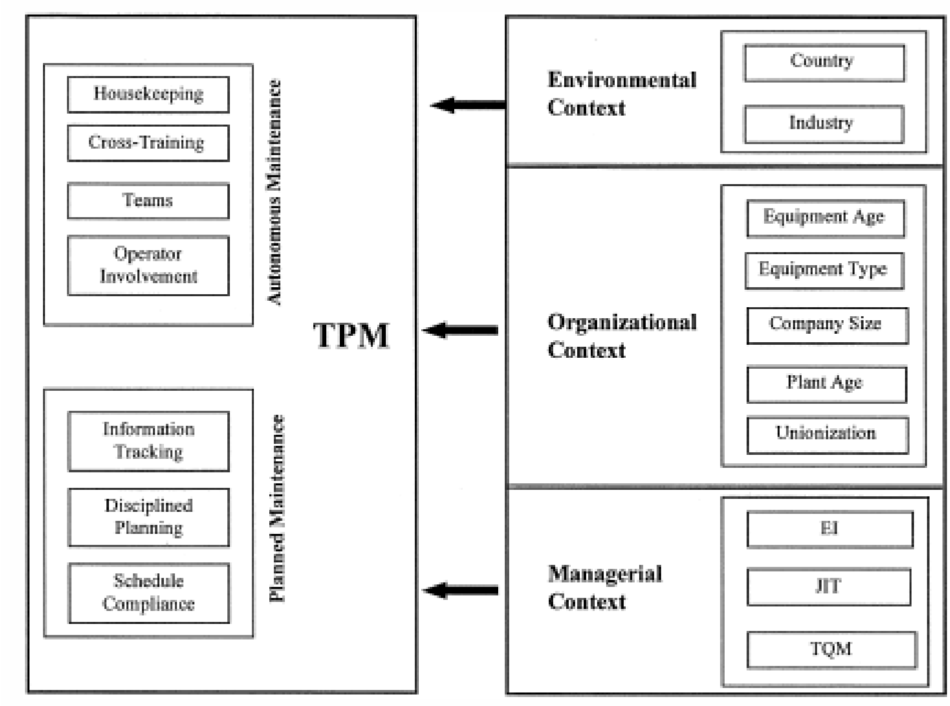


Figure 20: Contextual factors that influence TPM (Mckone K. E:, et al., 1999)

Focusing on the environmental context the main elements that affect TPM are the country and the industry in which is applied. Both of them have an impact on resources' constraint or support given, in one case by the strategic competition within the industry, in the other by governments' regulation. These variables affect the type of implementation but they are not significant as the managerial contexts, which are composed of JIT, TQM and Employee Involvement (EI)[27]. The implementation of TPM is essential for the fit with the other components of the lean philosophy. JIT needs strong planned maintenance system so that upkeep is conducted as scheduled rather than as a reaction to equipment problems. Therefore, we expect that JIT programs would be developed commensurate with TPM planned maintenance systems. All the machines have to be at the optimum status to perform without losses in quality. Only a complete upkeep system can drive the achievement a result of zero defects and support TQM principles. Organizational variables, as the others, have an impact on the implementation of TPM. The level of unionization of workers is the most significant because a company with many unionized members have more difficulties

[27] Employee involvement means that every employee is regarded as a unique human being, not just a cog in a machine, and each employee is involved in helping the organization meet its goals. Each employee's input is solicited and valued by his/her management. Employees and management recognize that each employee is involved in running the business.

implementing autonomous maintenance due to some constraints relate to the possibility of job rotation and multi-skilling. The size and the age of the company and the type of equipment are likewise relevant for continuous upkeep. The size is an important variable because larger companies are more standardized, centralized and formalized, and have more financial and human resources to deploy for the implementation of manufacturing programs. The age of the plant and equipment are indicators of the type of operating system employees adopt. The type of equipment (standardized or customized) influences the maintenance approach, particularly the type of training workers have to sustain. A customized machine entails more skills and knowledge for employees and the application of a different upkeep methodology with more tools.

All these components with the addition of human and strategic-oriented practices affect the four basic dimensions of Manufacturing Performance (MP) that are cost, quality, delivery, and flexibility. Maintenance programs have long been used as a means to control manufacturing costs. The results of the study of McKone (McKone K. E., et al., 2001) show that TPM does more than control the costs, it can improve dimensions of cost, quality, and delivery. TPM can be a strong contributor to the strength of the organization and has the ability to improve Manufacture Performance.

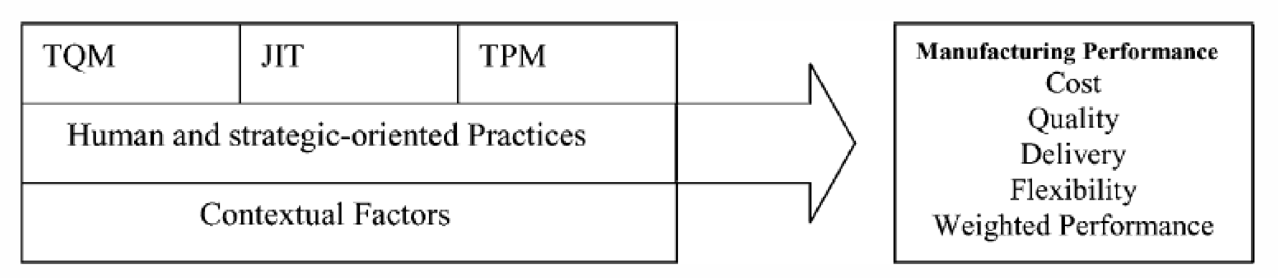


Figure 21: Factors that affect Manufacturing Performance (Cua K. O., et al., 2001)

Chapter 3

Fischer case

3.1 Fischer history

Fischer is a company of the group Fischerwerke GmbH & Co. KG, which operates worldwide (46 subsidiaries in 34 countries) and produces fixing systems both for firms and for end-users. Artur Fischer in Waldachtal, Germany founded it in 1948. The company becomes famous after the creation of the "S plug", a wall plug made from plastic (Polyamide), available in different shapes and sizes. Nevertheless, was with the management of his son, Klaus Fischer, which the company has become the leader in fixing systems. Klaus entered within the firm in 1975, and five years later, he became general manager. He bought Upat GmbH & Co. and ROCCA Bauchemie GmbH + Co., he decided to enter in the automotive industry by the creation of the CBOX, a plastic box that contains CDs for machines. This external growth was accompanied with an internal restructuring of organization: the adoption of *fischer Prozess System* (fPS), a revisited form of lean philosophy.

3.2 Fischer today

Now, Fischer distributes in over than 100 different countries while the production is located in seven nations. It has a gross turnover of about €711 million (2015), and 4,423 employees. Fischer has a wide range of products, and the core business is represented by fixing systems, other divisions are "Fischer Automotive Systems", "Fischertechnik" and "Fischer Consulting". The main division, Fixing Systems, counts around 14,000 articles. Property rights protect many of these products; indeed the firm has, sure enough, more than 1,500 intellectual property rights.

The company follows the following fundamental values:

- Innovation. We think and act with continuous improvement and renewal in mind in all company sectors. We are open to new approaches and embrace change. We thereby create further benefits for both our customers and ourselves across the world.
- Accountability. Each of us contributes proactively to the success of the group of companies. We are committed to productivity, value and achievement of the group goals, and we stand by our activities.
- Reliability. We respect the values of others, and are self-critical, trustworthy and reliable. We respect other cultures and their prevailing rights and standards, and expect our partners to do the same. We establish rules for ourselves and abide by them.

The branch Fischer Italia S.r.l. is located in Padova and support the entire national logistics. It counts around 300 employees and a gross turnover of €102 million (2016). In Italy, Fischer Italia provides 6,000 suppliers that are local metal wares, large retailers like Leroy Merlin, Brico etc., wholesalers, OEMs like Scavolini, Immergas and Lago, and other factories. Fischer Italia is specialized in supports for the sanitary system, and it has the research and development centre for this sector. The most important customer in this setting is Villeroy & Boch. Therefore, in addition to the standard production of fixing systems for mainly the national territory, the sanitary products are sold all over the world.

3.3 Fischer's "lean" philosophy

Klaus Fischer, son of the founder, decided to adopt the lean principle in 2005 and called it "fischer Process System" (fPS). The entire corporation implemented this approach, and all the goals are transferred to each subsidiary with the *Hoshin Kanri*[28] method. This system considers all non-value added activities as waste. fPS is composed of a defined framework (leadership culture, methods & tools and people development) in which the company has to operate eight process design principles (added value, transparency, flow, synchronization, process orientation, defect prevention, flexibility and continuous improvement). Leadership

[28] Japanese strategic planning process designed to ensure that the mission, vision, goals, and annual objectives are communicated throughout an organization, and implemented by everyone from top management to the shop floor (frontline) level.

culture is the ability to motivate people to achieve the company's vision and goals. To achieve this result the company has to create a high dissatisfaction for the current and achieved situation. Therefore, leaders encourage employees to surface problems and welcome them as potentials for improvements. People development consists of capitalizing on people's strength, and managing around their weakness. This is achieved with a clear definition of roles and responsibilities, so each employee, in the right position, grows his ability on their job and, subsequently, is able to solve problems easily.

"The biggest asset and most important success factor of our company are the employees – not machines nor real estate!"

Klaus Fischer

Finally, methods & tools are the way for improving the business processes by continuously surfacing and eliminating waste. Fischer classifies eight types of waste, in contrast with the traditional seven waste, considering unused knowledge as a waste to eliminate. In conclusion, adopting the "fischer Process System" the firm continuously avoids waste and does aim for a lean enterprise environment.

"Perfection isn´t attained if there is nothing more to add, it´s attained if there is nothing more to remove."

Antoine de Saint-Exupéry

The subsidiary of Padova have developed a deep implementation of fPS during these years. In particular, the adoption of 5S is completely entered in the mind-set of employees. Tidiness and order are the components that better explain the production department. In addition, the pull method is applied with the production plan using the *Kanban* board. Employees are also familiar with indicators, which are shown in big screens and in notice boards. KPIs are adjourned constantly each week, and, at the end of the year, the summary is reviewed together. Therefore, employees can understand the improvements achieved, and the margins of enhancement to pursue the next year. Nevertheless, the TPM, differently to the parent company, has not been implemented yet. For the year 2017, Fischer Italia has to start the adoption of TPM following the method proposed by the parent company.

3.4 Data about departments and machines

The plant is divided into three departments: injection moulding, automatic assembly and manual assembly. In addition there is another building used as a warehouse of raw materials and finished products.

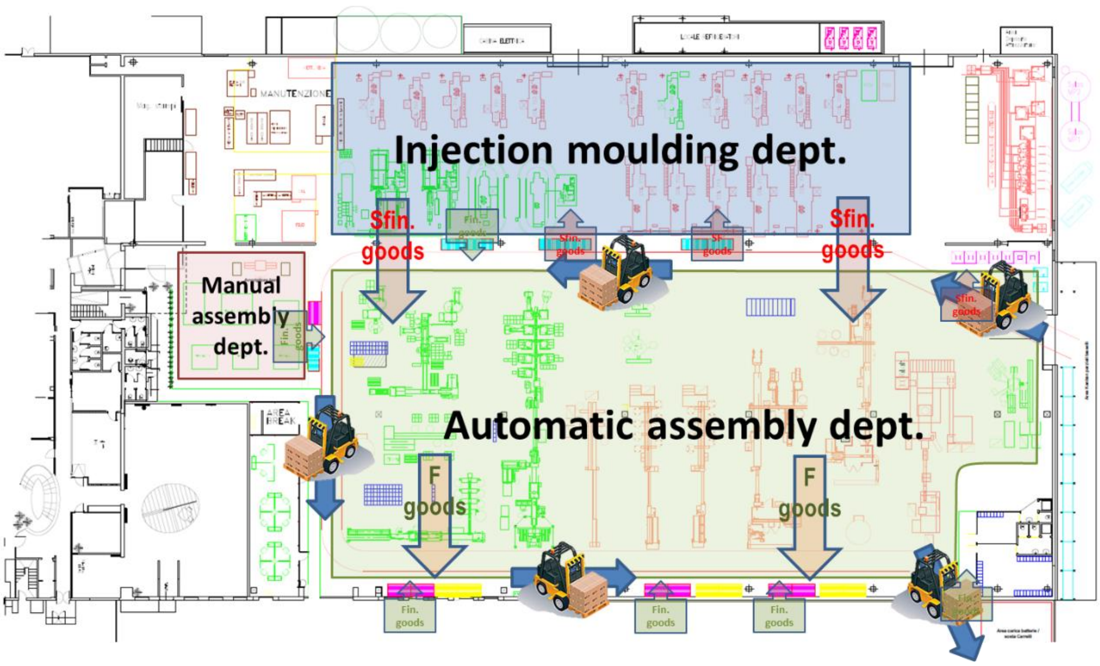


Figure 22: Layout of production (Fischer data)

There are twenty press machines dedicated to moulding and other fifteen dedicated to packaging (table 3).

Table 3: Machines of production (Fischer data)

DEPARTMENT	CODE OF MACHINE	TYPE OF MACHINE	YEAR OF PRODUCTION
MOULDING	701	Electric press	1979
	702	Hydraulic press	2008
	704	Electric press	2008
	705	Hydraulic press	1980
	714	Hydraulic press	1999
	715	Hydraulic press	1999
	716	Hydraulic press	1996
	717	Hydraulic press	1996
	718	Hydraulic press	1996

	719	Hydraulic press	1996
	720	Hydraulic press	1995
	721	Hydraulic press	1995
	722	Hydraulic press	1997
	723	Hydraulic press	1997
	724	Hydraulic press	1997
	801	Electric press	2007
	805	Hydraulic press	1997
	806	Electric press	2007
	807	Electric press	2009
	808	Electric press	2009
ASSEMBLY	Moonlight	Packaging	2004
	WB9	Packaging	2008
	WB2	Packaging	1993
	WB5	Packaging	2007
	Blister 418	Stacker robot	2005
	Blister 419	Stacker robot	2005
	Mikron	Assembly machine	1984
	Multipond	Weigher machine	1990
	Bustine 605	Vertical packaging	2001
	Bustine 607	Vertical packaging	1997
	Bustine 608	Vertical packaging	2003
	LPMBS12 (423)	Assembly machine	1996
	LPMBS12_4 (422)	Assembly machine	1996
	Avvitatrice 612	Assembly machine	2008
	Avvitatrice 615	Assembly machine	2008

Injection moulding department

The injection-moulding department consists of twenty moulding machines (six electric and fourteen hydraulic) that produce plastic fixings to be packaged. These machines get Nylon or PVC from big containers, positioned next to them. The presses heat plastic at around 290° and canalise the material into the stamps. Inside the stamps, the nylon solidifies taking the shape desired. These machines work continuously during the day. Unfortunately, the majority of the presses are very old, so they have many breakdowns and produce at lower pace than the presses of new generation. Indeed, to reach the demand the department has to get an OEE of 87% calculated on a base of 16 hours per day considering all days available. Given that the department cannot achieve this result, therefore the company has to launch the production during the night (22-6) without monitoring. Employees, which start working at 6 a.m., have to check the machines, and if necessary restore them. Inevitably, the efficiency during the night is very low and does not overtake the 50%. The production continues without interruption until 22 p.m., the end of the second work shift. In this department employees have to monitor the machines, control quality of output, change stamps when the batch is completed and replace containers full of finished products with empty ones. Each worker is also responsible for the autonomous maintenance and tidiness of the machine. These containers are transferred to the assembly department for packaging. This department approximately works at an OEE level of 89% (considering only hours of production) (fig. 23). The level is very high because the machines are automatic and there are mainly two sources of downtime: breakdowns and set-up. There are eight workers entirely dedicated to this department. One group works from 6 a.m. to 2p.m., the other from 2p.m. to 22p.m. These groups are composed of four persons: one worker is completely dedicated to machine n ° 808, which consists of the moulding, and the assembly machine connected, the other two are dedicated to the remaining machines, and the last one is responsible for changing stamps, according to customers' orders. These operators are supervised by the responsible of production, who manages the production pace putting *Kanban* to the assigned machine.

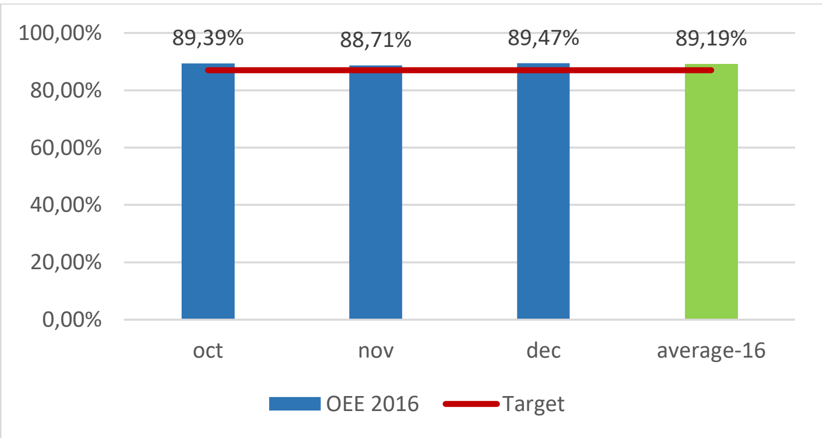


Figure 23: OEE of moulding department (Fischer data)

Automatic assembly department

The packaging department consists of fifteen machines, more recent than the press department. Some machines are automatic, but the majority of them are semi-automatic, requiring a constant contribution of operators. In this department, the semi-finished products created by the moulding department are assembled with metal components that come from external suppliers. The finished products are positioned next to the machine, and a train, each 15', picks up them and locate in the warehouse. In the same path, the train brings metal components necessary for packaging from the warehouse. Workers have to control the production, operate the setup, and renew the container of raw materials, like plastic packs or blister. As the moulding department, they perform the autonomous maintenance activities and clean the machine when necessary. The assembly machines are younger than the moulding ones, they perform better also because they have a lower utilization ratio. They do not operate at night, and some of them works 8 hrs per day, others 16. However, these machines, instead of the moulding department, require a constant presence of operators because there are many operations to take care of. Twenty-two workers manage machines that have an OEE from 45% to 78%. The majority of the losses are related to minor stoppages and frequency of set up. In 2016 this department has reached a OEE of 66,36% two points over the target set at 64,83%. The target for 2017 was set at 69,68% (+5% of the average of the previous year).

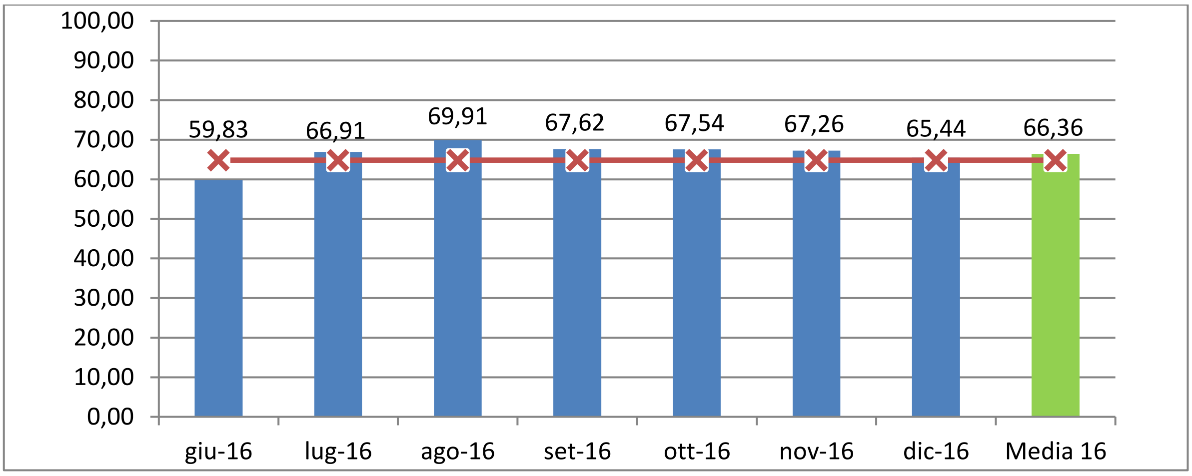


Figure 24: OEE of assembly department per machine (Fischer Data)

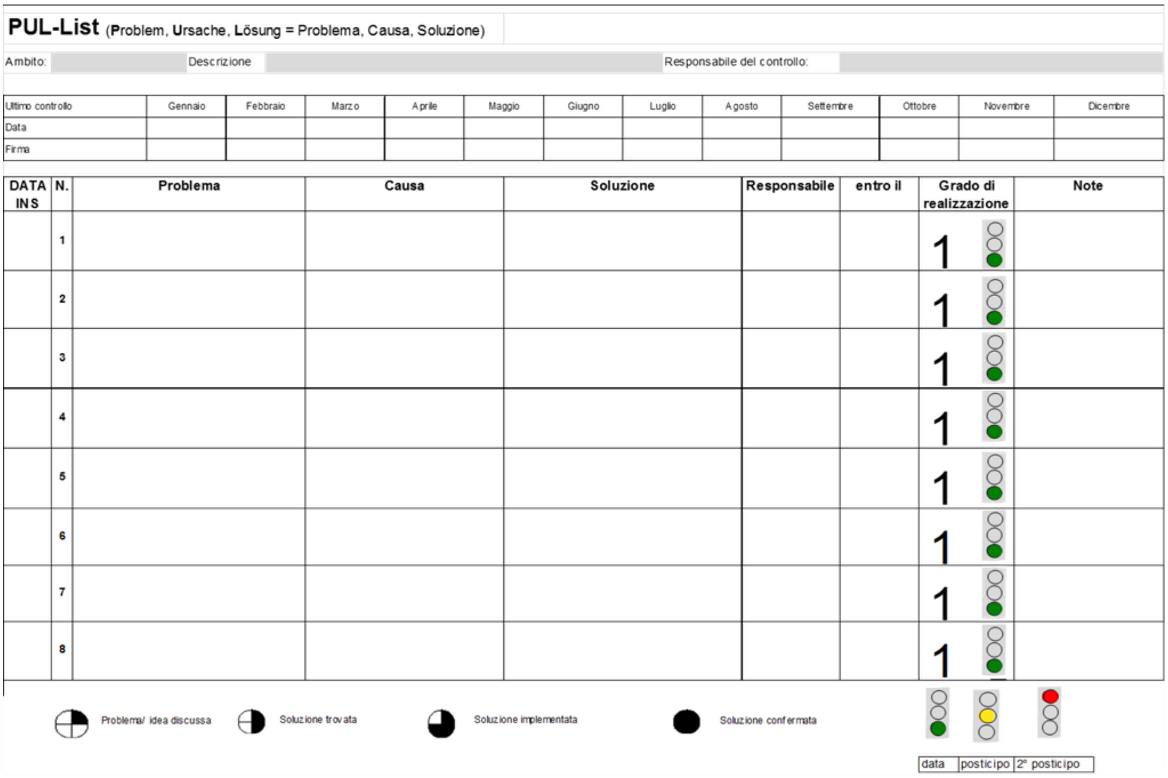
Manual assembly

In the manual assembly department there are four workstations for assembling parts. Two workers are fixed in this department, and assemble some articles that cannot be processed by the machines. They are also responsible for the management of returned goods for no compliance. In the case of particular orders of big dimensions some workers of the assembly department are used in the manual one to complete the batch on time.

3.5 How maintenance works in Fischer

At the moment the company operates in a situation of emergency because there are continuously breakdowns that jeopardize the production's pace and the planned maintenance schedule. Therefore, the maintenance team has not enough time to perform upkeep activities as scheduled. It is common having simultaneous breakdowns within the production plant. In that case, the maintenance team perform the repair analysing the priority of the machine by the type of product or the importance of the customer. Planned maintenance activities are divided in ORDPROD, ordinary activities completed by production workers, and ORDMAN performed by maintenance operators. When upkeep operations are not feasible internally, the firm has to contact an external company, the firm that produces the machine. These ORDEST activities are inserted in the database of investments, and are performed only after a quote. Maintenance is emitted immediately for expenses <1500€, instead for investments between 1,500€ and 5,000€ it is necessary the authorization of the technical manager. For expenses >5,000€ it is necessary the entire *iter* of authorization within the firm. Each single operator manages autonomous maintenance periodically, while the maintenance team performs extraordinary upkeep. There are three operators completely dedicated to maintenance. All the upkeep activities are registered in a software, called MP2. There are in total 529 maintenance activities, which have to be performed with different frequency during the year. All the upkeep actions of the week are printed and sent by an operator to the maintenance team, positioning it in a board. Here each paper is entrusted to the correct employee. The worker has to complete the maintenance activity and report in the paper the job done, the time spent and the parts changed. In this paper are registered also additional interventions not included in the sheet, so it is difficult to understand when the machine needs replacement parts. All the reports are inserted manually into two different software:

MP2 and SAP. Inserting in SAP the time spent for the upkeep, the system counts automatically the cost for each intervention. If there is the necessity of new spare parts, materials or external intervention an order is delivered. When the material and the relate invoice arrive at the firm, the cost is allocated to the machine. In a situation of extraordinary maintenance, the operator who performs the upkeep has to complete a sheet indicating the problem and the changing parts. These upkeeps are inserted manually categorised in mechanic (STRMEC) or electric (STRELET) intervention. The upkeep is applied also to stamps of moulding machines. Each stamp has to be cleaned after a predetermined number of pieces produced or restored when it has a problem. A dedicated operator continuously cleans and lubricates stamps. These activities are registered in the same software. The continuous problems of the two departments make difficult the completion of the entire plan of ordinary maintenance as scheduled. In some cases the intervention is postponed, in other cases it is impossible to be performed. On the whole, around the 70% of scheduled maintenance are performed in 2016. In addition to these planned or unplanned operations, the maintenance team produces some components or modifies machines to improve the productivity. These activities are registered as activities of improvements (ATTMIG) and are defined at some meetings in which the production managers, the team leaders of the three department and the maintenance team analyse the weaknesses of a specific centre of work. It is clear that problems' discussion follow a top-down approach. Therefore, operators are outside the decision planning process (no structured meetings) and managers take on evident problems, like quality complaints or KPIs' variations. In this situation, all the actions follow a reactive approach, not proactive as lean's creed. At this point the interventions are listed in the PUL-List (fig. 25) indicating the problem, the root cause, the right solution, the person who makes the improvement and the time of completion.


PUL-List (Problem, Ursache, Lösung = Problema, Causa, Soluzione)

Ambito: Descrizione Responsabile del controllo:

Ultimo controllo	Gennaio	Febbraio	Marzo	Aprile	Maggio	Giugno	Luglio	Agosto	Settembre	Ottobre	Novembre	Dicembre
Data												
Firma												

DATA INS	N.	Problema	Causa	Soluzione	Responsabile	entro il	Grado di realizzazione	Note
	1						1	
	2						1	
	3						1	
	4						1	
	5						1	
	6						1	
	7						1	
	8						1	

Problema/ idea discussa Soluzione trovata Soluzione implementata Soluzione confermata

data | posticipo | 2° posticipo

Figure 25: Pul-List (Fischer data)

	jan	feb	mar	apr	may	june	july	aug	sept	oct	nov	dec
Hours budget 2016	**482**	**595**	**623**	**567**	**623**	**567**	**595**	**510**	**623**	**595**	**595**	**425**
Hours completed	491	713	787	639	729	739	632	492	612	667	687	315
Hours budget 2017	**552**	**526**	**604**	**473**	**578**	**526**	**55**	**578**	**552**	**578**	**552**	**473**
Hours completed	590	567	681	488	733							

Table 4: Hours of maintenance in 2016 and 2017 completed by the maintenance team (Fischer Data)

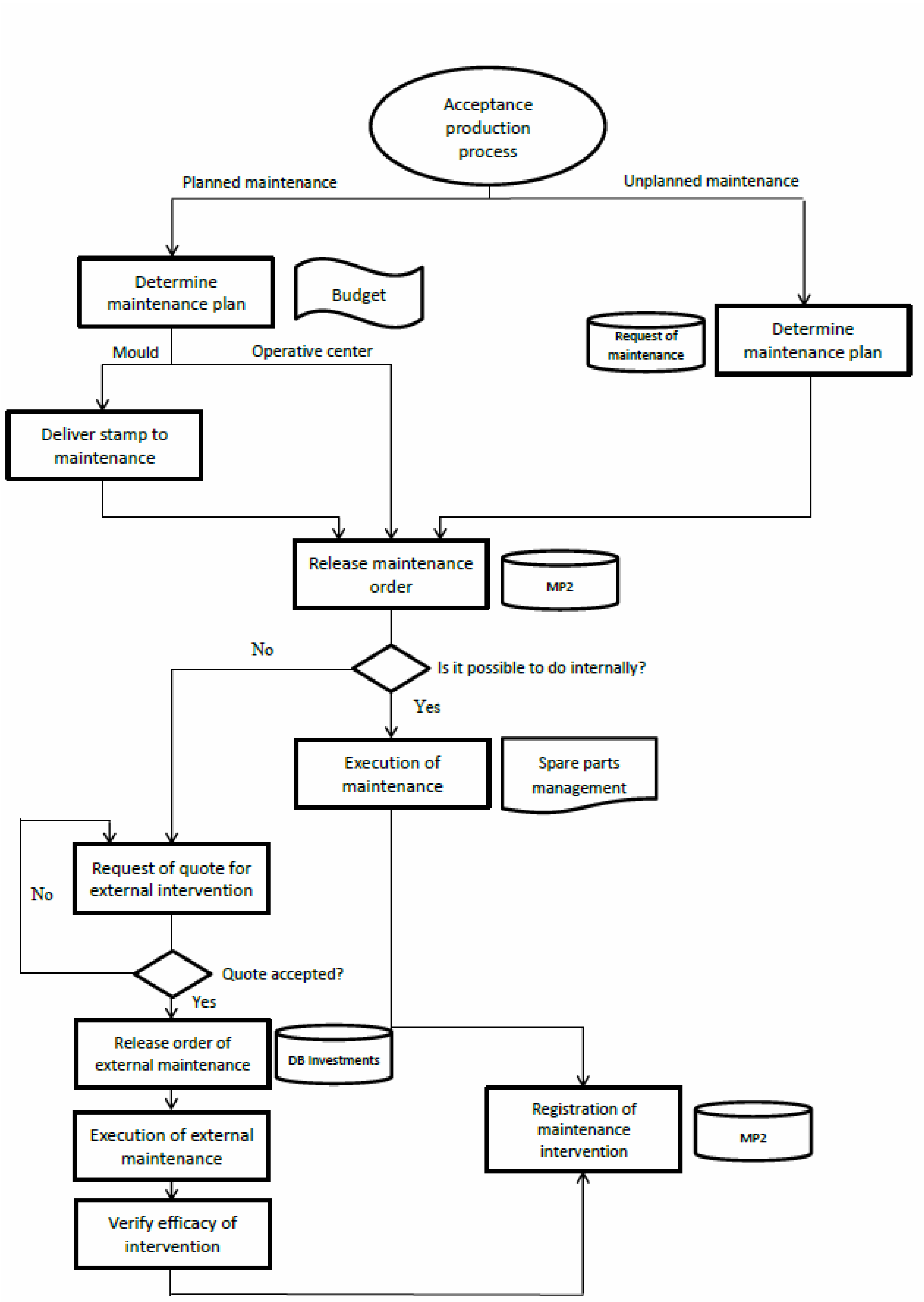


Figure 26: The maintenance system in Fischer (own elaboration)

Indicators of performance

In terms of indicators, the firm is well structured. Each centre of work has his own board in which there is a description of machines, the OEE level, the main sources of downtime and average setup time. In addition, there is also *Kanban* board for visualize the quantity that has to be produced, divided per product.

The most important indicator connected to maintenance is OEE. In Fischer Italia it is calculated matching two different sources of data. Part of data are inserted manually by each operator (MYPROD software). These results are not so much reliable, due to forgetfulness and errors (human factors). Anyway, this system permits the analysis of the motivations of failure and downtime. MYPROD is a software currently in development, which shows OEE, analysis of downtime and technical data sheet of each machine. This source of information is important to categorize the downtime into one of the six big losses. That helps the division of breaks to calculate the three components of OEE: availability, performance and quality. These data are visible in real time in the screens positioned in the *gemba* but also can be monitored remotely using smartphones and tablets. The other software, called MDE, registers automatically when the machine is producing or not. This system is not able to calculate OEE correctly because it considers also the night as downtime, but it has the advantage of measuring correctly the time of stoppages but not the motivation. The connection between the two systems gives one complete information from which it is possible to idealize future improvements. Before the implementation of these two systems, the motivations of stoppages were not reported, and the data were not real. Therefore, OEE was too high due to wrong calculations of downtime from employees, always in deficiency. From 2016, the data are available and more realistic due to increased awareness of workers to the new system. The adoption of MYPROD started in January 2016 but achieved a complete adoption in June for the assembly department, and in November for the moulding department (fig. 27). At the moment indicators are not much significant, in particular in the moulding department. Anyway, this software is an important starting point for improving the organization of processes, the knowledge of others operative centres for each operator and the flexibility between each centre that can be activated only when necessary. The adoption of the new software is the first step to industry 4.0.

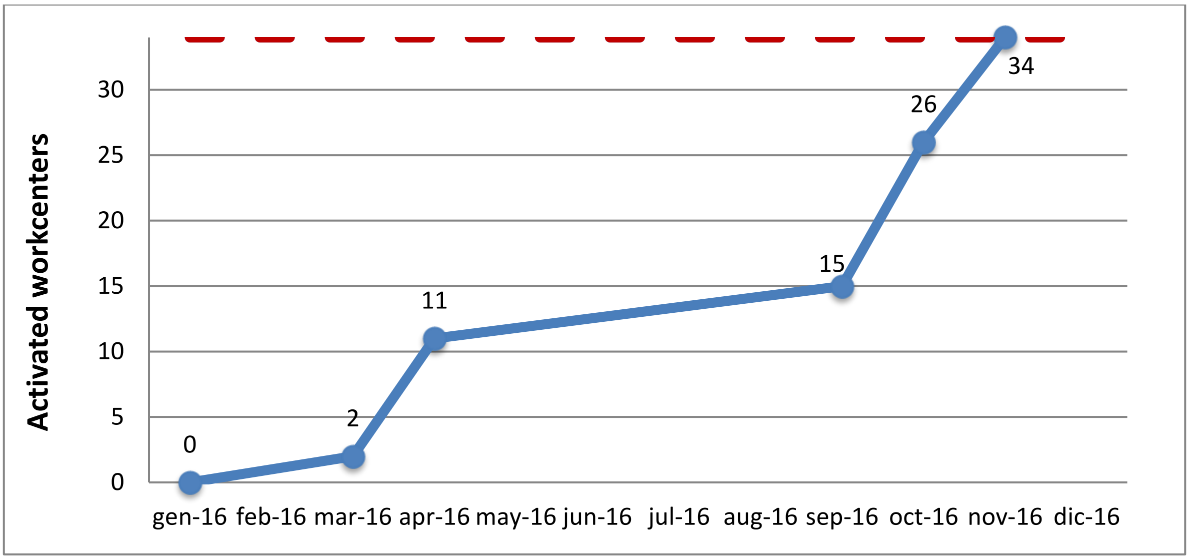


Figure 27: The adoption of MYPROD in 2016 (Fischer data)

Strictly connected to downtime, it is important to measure the service level of the firm. This indicator show the capacity of the firm to ship material in time to customers. In 2016, Fischer Italia has not achieved the target of 95%. Another important indicator of production department is the degree of absenteeism. This is important for measuring the satisfaction of employees within the organization. The target of the firm is fixed at 97%, and in 2016 the objective was achieved with a result of 98,1%.

At the moment the firm, excluding the OEE, has not indicators connected to maintenance. They have to be chosen and analysed.

3.6 TPM for Fischer

Fischer, as the lean approach, has developed his own maintenance system. For Fischer, Total Productive Maintenance is a mix of three maintenance dimensions: autonomous, preventive and planned (fig. 28).

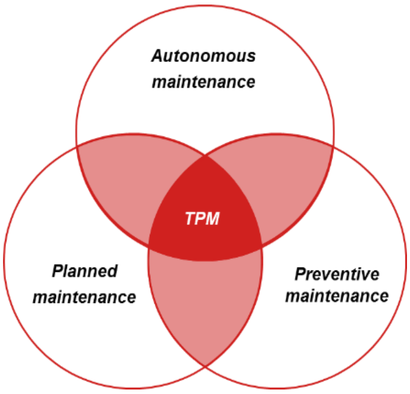


Figure 28:"Three pillar model" (Fischer data)

Each maintenance component has many dimensions, looking into details:

- Autonomous maintenance: All the employees have to observe the weaknesses of the machine, listen and see to monitor the equipment. In addition, they have to clean the machine periodically. Cleaning is important, because it gives a deep analysis of possible deficits and problems of the equipment. Workers have to perform the upkeep, and develop its activities. They do not have to forget to report the activities performed[29] and deficits emerged, which will discuss during shop floor meetings. Employees have to perform, as regards to the TPM level achieved, all the seven activities of AM after having sustained a focused training. These steps and the related training are listed in the following image (fig. 29).

[29] All the autonomous maintenance activities are represented in a paper attached to the machine. Next to the activity there is the frequency and some space in which the operator certifies activity's culmination.

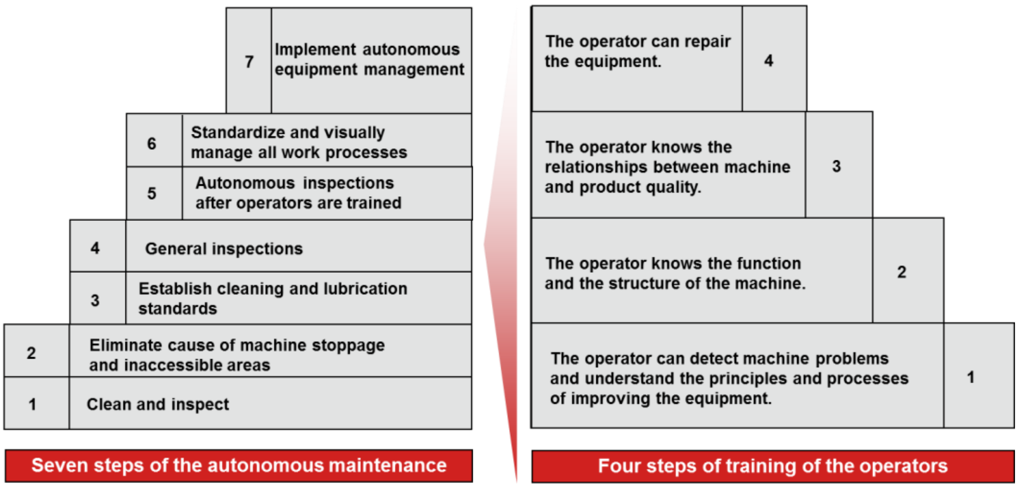


Figure 29: Seven steps of the autonomous maintenance

- Planned maintenance: This type of maintenance has to be performed following a schedule, developed and perfected over time. Workers have to repair deficits in order of priority and to manage spare parts. Prioritization depends on the type of product or the client that waits for the order. The restoration is not enough, because after fixing the problem employees have to develop and implement new solutions or countermeasures to avoid the problem in future. The management of maintenance information is another important component for future analysis. Fischer considers six steps of planned maintenance (fig. 30).

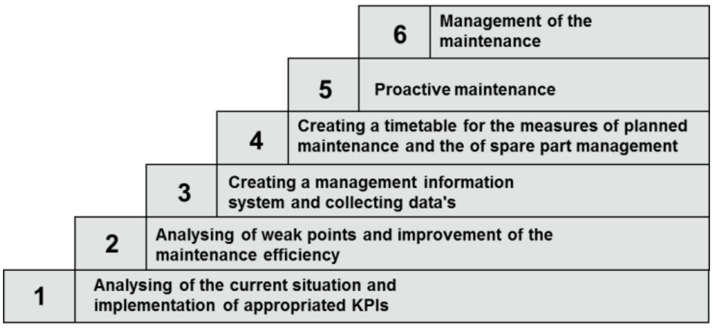


Figure 30: Six steps of planned maintenance

- Preventive maintenance: The third component of maintenance consists of checking and optimizing the machine, collecting information and developing solutions. All the resources collected are necessary for reengineering existing machine to make them performing better. The next step is the creation of a new maintenance plan for new equipment. All the developed maintenance activities have to be taught to employees. All the preventive maintenance steps are resumed in the following figure (fig. 31).

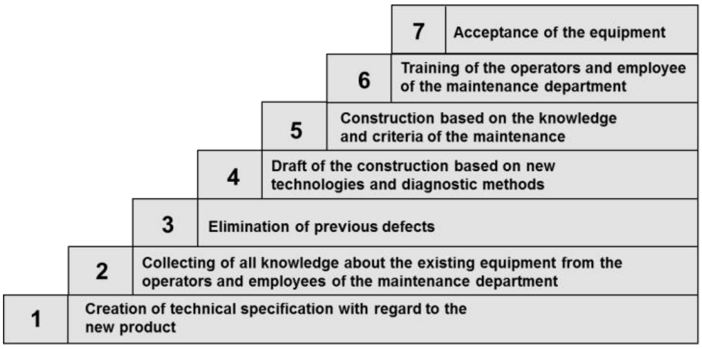


Figure 31: Seven steps of preventive maintenance

The maintenance system in Fischer Italia has been improved over time. At the moment the parent company has advised his branches to focalize on TPM to achieve better results and minor stoppages. This new upkeep approach has to preserve employees' safety (one of TPM pillars). The total implementation of TPM follows a complex route. With the implementation of the ultimate level, the firm could be able to reach an OEE higher than 85% as the World Class Manufacturing[30].

At the moment the firm has to start the first level that consists of:

Type of maintenance	Activities
Autonomous maintenance	TPM instruction for all employees
	Responsible persons for TPM facilities defined and visualized
	Kick-off and define targets (OEE)
Planned maintenance	Temporary maintenance plan hold-up analyses with measures
Preventive maintenance	Create technical specification referring to required plant

[30] World Class Manufacturing represents the best builders of goods or services within the world.

Each step of the three dimensions can be represented as a level of the so called "TPM House" (fig. 32) in which only the completion of the three different maintenance systems is necessary before start thinking to the upper level.

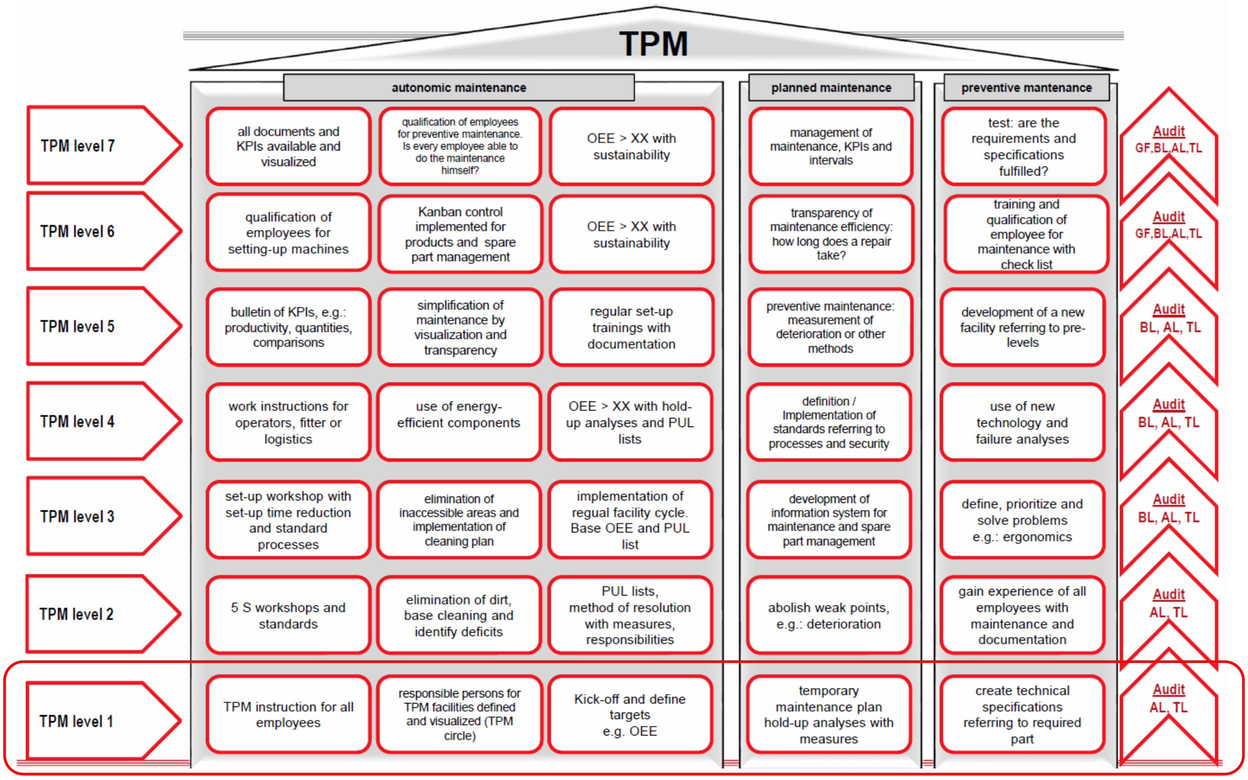


Figure 32: Fischer's TPM House (Fischer data)

First TPM has to be taught to employees with a standard lesson and a successive planning of regular meetings, which have to be organized considering the machines and the team. At these meetings the participants are the team leader, the responsible of production, the responsible of maintenance and, finally, the operators responsible for the group of machines. The main contents discussed are the implementation of new measurements using the tool of PCS (problem, cause, solution) points[31]. Between TPM meetings each employee has to focus on PUL List, and make in practice maintenance activities to pursue a complete realization of ideas discussed. When all components of the level of the TPM House are completed, the team leader and the responsible of production close the audit proving and signing the reality

[31] Each team has to complete the PUL-List (Problem, Ursache, Losung = Problem, Cause, Solution) indicating the problem, and for each the proposed solution. These countermeasures if approved are implemented as new standards.

execution of all the steps. Only when the first level is complete it is possible to start the upper ones.

At the moment the application of TPM is partly completed in two machines: Moonlight and WB9. In these two centres of work all the activities of autonomous maintenance have been completed and sustained. Sure enough, operators have already attended the course of TPM, nominated the responsible of TPM, and set the targets of OEE. In addition, these lines have improved TPM adopting some tool of the second level (5S, identification of deficits and standard processes). The other machines have not started the implementation yet.

3.7 TPM implementation (Level 1)

The implementation of TPM is applied to thirty-five different centres of work with likewise machines, using the guidelines previously analysed.

Following the schedule below the implementation of TPM starts with a deep analysis of the current situation ("as is") of maintenance and machines. In particular, collecting data of 2016 are created many indicators to be studied and fixed as a basis for comparison in TPM implementation. It was improved the OEE calculation, with a better cohesiveness between MDE and Myprod. Having a right indicator was important for fixing a target OEE to achieve at least in June. The assembly department counted an average OEE of 66,88% in 2016 and the target for the 2017 is set at 69,68% (+5% respect to the previous year). Instead, the moulding department didn't have a trustworthy OEE, so it was decided to recalculate considering also the production at night on a base of sixteen hours per day (the time of the two shifts). Nevertheless, the target for moulding machines is set at 87% considering day. It is the level under that the firm is not able to serve customers on time.

In addition to this indicator, many others have been analysed, in particular the hours spent for maintenance per machine, the average delays before completing ordinary maintenance, n° of extraordinary maintenance, n° of activities of improvement, mean time to repair and mean time between failures. These ratios are important for having a complete imagine of the situation before the change. Each operator has been instructed about TPM logic. This makes possible the creation of a positive atmosphere before the improvement. The lessons put attention mainly on the problems of the current situation and the future possible results attainable. Certainly, the presentation includes also a short description of what TPM is and what workers have to do to perform it properly. The lessons are instructed in January to the moulding department and in February to the assembly department.

Description of kick-off

The implementation of TPM is sustained by the implementation of TPM boards. All the employees are divided into teams, grouping together similar machines. In the moulding department are created four teams that have to manage around five moulding machine each. In the assembly department the fifteen machines are grouped considering some similarities. The best solution is the creation of eight groups managed by likewise teams. Each week two teams participate at a fifteen minutes meeting. That means that in about one month and half each team has explained problems and possible improvements.

Department	**N° of team**	**N° of machines**	**N° of participants**	***Of which operators***
Moulding	1	5	4	1
	2	6	4	1
	3	5	4	1
	4	4	4	1
Assembly	5	1	4	1
	6	1	4	1
	7	2	6	3
	8	3	8	5
	9	2	4	1
	10	2	5	2
	11	1	4	1
	12	3	7	4

Table 5: TPM groups (Fischer data)

Each team has his own board in which are showed the members of teams (TPM Circle), the PUL List, the images of activities to be performed to resolve problems explained in the PUL List and the percentage of completion of the audit. Each team, in addition to operators, contains the responsible of production, the leader of the maintenance team and the supervisor. The operators and the supervisor have to draft the PUL List indicating, the machine and the related problems. All the problems highlighted are discussed during regular meetings and the right countermeasures are decided to overcome definitely weaknesses. The solutions are discussed with the maintenance responsible who has the final word about the feasibility and the effectiveness of the interventions proposed. According to these conditions to each improvement is fixed an expiring date as a result of the priority assigned to each improvement or preventive maintenance. All these solutions have to be standardized to the single machine in question or, if it is possible, to other similar machines of the group. At these meetings the indicators of maintenance are analysed and compared with the past. For each machine, or group, it is possible to measure the number of ordinary and extraordinary upkeep, mean time between failure, mean time to repair and the number of autonomous maintenance done.

Planned maintenance programs and Analysis of the errors

The planned maintenance program is an update of the previous one. The switch to another software "Geoweb" was important for data cleaning, and for re-planning some upkeep programs. Frequency of upkeeps are checked and updated due to the experience of the maintenance team. Many new upkeeps have been added, and some other, not appropriate to the machine, have been deleted. The new software give us the opportunity to delete all data regarding to equipment already sold or scrapped. All the historical data of maintenance were transferred to the new software and studied to adopt right countermeasures. These countermeasures were discussed with the operators, the only people who knows why the same problem continues to happening.

Preventive maintenance

The last objective of the first level of TPM is the creation of preventive maintenance for a part for operative center. This means that for each machine a component has to be analyzed in details and, with the support of responsible operators, a dedicated program of preventive maintenance must be created and adopted. It is fundamental to sensitize each operator using all their senses to notice any abnormality and report immediately. That can be achieved only with a great sense of cohesiveness inside the team, and a moderate level of competitiveness within each team. The exchange of information is important for the planning of the right intervention, possibly when the machine is not working.

MEASURES	COMPLETED BY
Situation “As is”	29/09/2016
Preparation formation	31/12/2016
Formation of employees	31/01/2017
Arrangement showcase in moulding department	31/01/2017
TPM Circle	20/01/2017
Target OEE	31/01/2017
Populate showcase	28/02/2017
Planned maintenance programs	30/04/2017
Analysis of errors	31/5/2017
Creation of preventive maintenance for a part for operative center	31/5/2017

Table 6: Schedule of TPM implementation (Fischer data)

Chapter 4

Results achieved and contextual factors

According to the model proposed by Kathleen E. McKone, Roger G. Schroeder and Kristy O. Cua (1999), this thesis wants to make in evidence the impact of the contextual factors in the implementation of TPM. Despite to the model, which explores the contextual differences of plants to better understand what types of companies have adopted TPM programs considering three different contexts (environmental, organizational and managerial), this thesis wants to analyse in detail the impact of the operative context inside a single firm, Fischer Italia. Environmental context is not considered because the TPM program was imposed by the parent company (which have already overcome the third level of TPM House), therefore the firm has not any margin to correct this approach even if the companies have different environmental forces to challenge. This analysis consists of a collection of three months data after the implementation respect to the past. The majority of the data are evaluated respect to the previous year (2016), in particular October, November and December. This model, applied to thirty-five different centres of work, wants to show how variability affects the increase or reduction of some sources of performance (dependent variables). These factors can be divided into two different categories: which are operative and which are more technical based because they represent machines' characteristics. This model analyses nineteen contextual factors per each centre of work. These factors are:

- equipment age,
- n° of machines involved within centre of work,
- equipment dimensions,
- difficulty to manage maintenance,
- number of planned maintenance per year,
- n° of ordinary maintenance done in 2016,
- % of ordinary maintenance done in 2016,
- n° of autonomous maintenance done in 2016,

- n° of activities of improvements performed,
- type of machine (manual/automatic),
- utilization rate (in days),
- hours of production per day,
- average n° of setups per month,
- average time per setup[32],
- n° of products managed by the machine,
- workers per age,
- n° of workers per shift,
- years of experience of workers.

The sources of performance contemplated are twelve: Δ OEE, Δ time for maintenance, Δ number of extraordinary maintenance, Δ mean time to repair, Δ mean time for intervention, Δ activities of improvements done, Δ hours spent on maintenance, divided into activities of improvements, ordinary and extraordinary maintenance, Δ preventive maintenance done and Δ hours dedicated to preventive maintenance.

4.1 Results achieved

The improvements achieved, measured with Δ indicators of performance, show that the implementation of TPM has increased the level of the OEE of around 1,31% for the moulding department and 2,61% for the assembly department. It is reassuring that the improvement has been almost fixed during three months, but not raising constantly. Anyway the graph (fig. 33), supported by the trend line, shows that this improvement is consolidated and can be a base to grow once again.

[32] Average time per setup is not an indicator of performance, but a source of variability, because the firm has not spent much time on setup improvement. The reason is that the development of SMED approach will be contemplated at the third level of TPM, after the implementation of the 5S.

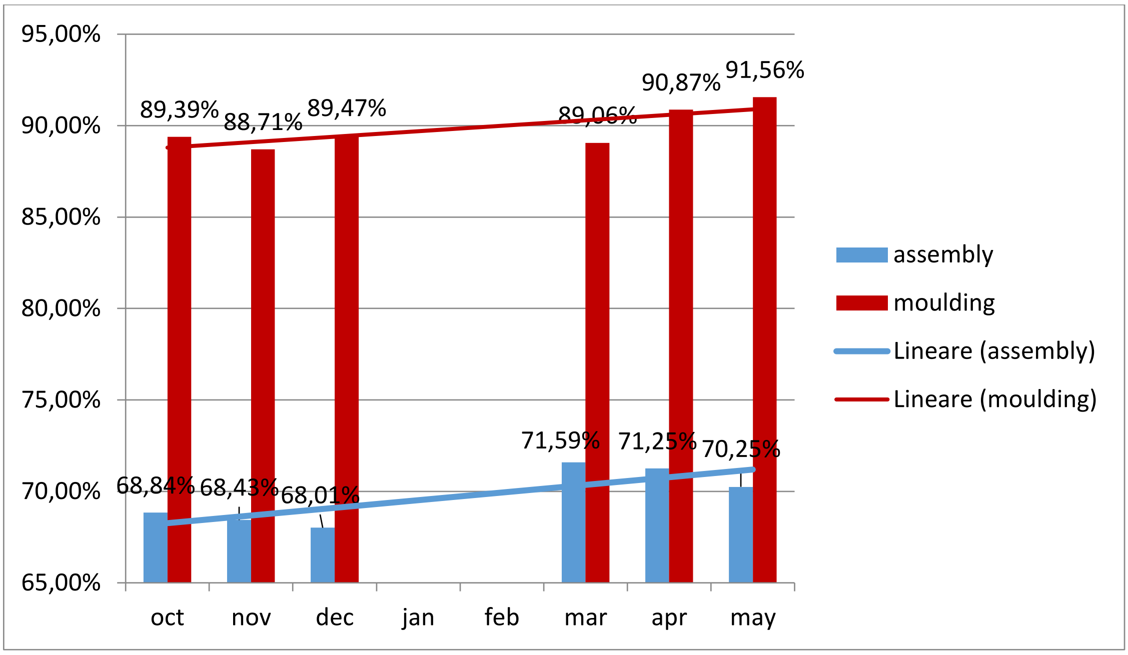


Figure 33: OEE before/after TPM implementation per department

Numbers show that the improvements have an impact in the majority of the machines. In particular, there is a reduction of the spread of OEE, from 48% to 40%. This result is very meaningful because, generally, machines with lower OEE have improved more than high performance equipment.

Figure 34: OEE improvement per centre of work (Fischer data)

On the whole there is a reduction of the number of downtime of 1,41 (-1,5 in moulding and -1,23 in assembly department) due to a consistent increase in mean time between failures +19,4 days (+21,86 in moulding and +16,09 in assembly department). Average time for repair and average time for intervention are remained approximately constant (both of them with a reduction of 0,29h). The number of activities of improvements has not changed during the implementation (-0,14). In support of the results already explained, there is the fact that the hours of maintenance performed for each machine, before the implementation, are on average 3 hours more than the hours spent after the implementation. So the improvements achieved are not related to a higher availability of time (882 h oct-dec, 777 h mar-apr). These results are surely been achieved due to a better allocation of upkeep hours available. On the whole there is a substantial increase of time dedicated to ordinary maintenance at the expenses of activities of improvement. As a result, there is a sensible reduction of hours spent on extraordinary activities. This can be explained by is the adoption of the preventive maintenance, performed on suggestion of employees during scheduled meetings or in any circumstances. These types of maintenance are performed mainly when the machine is idling or if it is not possible when the machine is not saturated. These new types of activity have been probably the best impact on performance. Almost entirely activities are performed in the assembly department due to the fact that these machines have higher level of visibility and lower inaccessible areas. Therefore, it is easier to use senses to understand something wrong. In these three months, the maintenance team have performed twenty-seven preventive maintenance (amounting to 115 hours), that in many cases have avoided many breaks.

4.2 Correlations between indicators of performance and contextual factors

As previously said, this model (fig. 36) wants to analyse the correlation between indicators of performance (dependent variables) and operative variables (dependent) in which there is a significance above 90%. The study shows many consistent correlations that impede or facilitate the implementation of TPM. Looking into details:

Factors that affect OEE

Considering the most important indicator, OEE, it is self-evident that biggest improvements are achieved in the assembly department where the utilization rate (in days) and the hours of production are lower (respectively -0,32 and -0,43). These two variables are in relationship because machines that work more, in terms of hours, are which that have a higher utilization rate in days (0,4091*). Anyway, the result is consistent with both of them because the OEE computation is evaluated when the machine has an operator that register his presence. For this reason, days of no production do not affect OEE. As a result, it is clear that machines that produce more have higher obsolescence rate, so, the implementation of TPM, even if it has a positive impact in performance, cannot revolutionize the results. Furthermore, these two variables are strongly correlated with the difficulty to intervene in machines (around 37%), so time for downtime can be reduced less than the other machines. In addition, machines that have a lower utilization rate can be controlled better and for a long time, instead the others have to be inspected faster due to their relevance on firm's service level. It is clear that, in the assembly department, improvements and preventive maintenance activities can be performed when machines are not producing, while all the activities related to the moulding department can have an impact on machines' downtime.

To validate the importance of the role of ordinary and autonomous maintenance the best improvements are achieved where these activities were not performed so high. In particular autonomous maintenance is performed more in machines with higher utilization rate and hours of production, respectively 0,3905* and 0,6302*, so there is a strong relationship with the situation explained before. These correlations explain that a high control level reduces the possibility of downtime. The better allocation of maintenance hours in terms of ordinary activities has immediately reduced the gap in terms of OEE between machines with high and low levels of care in 2016. It is unexpected that the equipment age has no impact on the improvement. This can be considered an incitement to perform the maintenance program without distinctions between machines' age.

Factors that affect time of intervention

The correlation between mean time of intervention and equipment complexity (0,3754*) shows that the machine's design is fundamental for an easier fulfilment of cleaning and fixing. These machines require more time to dismantle, fix and then reassemble. In addition, as for the OEE, the difficulty to intervene in the machine is related to the utilization of machine in terms of hours and days. It is self-evident that there is a strong correlation between OEE and mean time for intervention (-0,6483*). The results show that the highest improvements in OEE have been achieved in machines in which the time for intervention has decreased less. The small enhancement achieved is obviously related to the reduction of hours of extraordinary maintenance, but it is a result that can be twisted positively in the long time. In the short term all the information possessed by employees melded with maintenance team know-how can bring to a positive but delimited modification of the machine. The most important improvements are which related to the reduction of inaccessible areas (TPM – Level 2). Nevertheless, in many cases it is not possible to modify the equipment, so the knowledge has to be stored and later used in case of a new machine's purchasing. A customized equipment will permit to reduce first common downtimes and, secondly, time spent per intervention: ordinary, improvements and extraordinary activities.

Unexpectedly no-one factor has any correlation with "mean time to repair" and "mean time between failures".

The model shows that the reduction of hours dedicated to activities of improvement are strongly related with the average hours of production and utilization rate of each machine. In particular, a lower reduction of hours for improvements is related to machines that produces for longer time. This is explained by the fact that equipment that produces for two shifts (around 16 hours) have greater relevance than the other. Therefore, the decision to maintain generally unchanged the effort on these machines and to reduce for the other equipment, was pondered to increase the availability for ordinary upkeep.

Time for extraordinary maintenance is related with machines that are more saturated in terms of days and not hours of production. The correlation (0,3894) shows that the machines that work less days than others have achieved a higher saving in terms of hours of maintenance. This is strictly connected with the obsolescence of the machine and in particular with the seriousness of the problems that a machine that works constantly have, instead of which that works occasionally. As a consequence it seems that the strain of a machine that works all the days available is higher than which operates for more hours throughout the majority of the days.

These results show that a correct maintenance program has, in the short term, higher impact in machines that work less.

The improvements about OEE and reliability achieved are exposed in TPM boards to increase the awareness within operators that the work started is reaching the targets.

Factors that affect preventive maintenance

The variable "n° of preventive maintenance" is the most important of the model because it is the first time that maintenance technicians adopt this approach following operators' reports. It is clear that these twenty-seven preventive maintenance activities, performed in three months, have revolutionized the most the upkeep system. This new approach offers the possibility of a deep analysis.

There is evidence that these interventions are performed mainly in machines in which there are more operators. This is the case of the management of complex processes (n° of setup, n° of products managed) or big machines. Each of these variables is correlated with preventive maintenance. In the case of a machine managed by two workers during the same shift, there is an increased possibility of movements around the equipment, so a better vision of the entire process. A higher number of dedicated employees is fundamental in the observation of possible components' deterioration. Each operator has to use his five senses to analyse any problematic and subsequently report to the maintenance team. This organizational programme makes possible the communication between operators, essential in the problem detection and in the ideation of right solution to eliminate the weakness forever.

The number of setup have an important role in problems identification. Setups force workers to move around the machine. The operator that stays in a fixed position for the entire shift have lower probability to see and to detect any malfunctioning that occurs far from him. This concept is strictly related to the dimension of the machine: bigger machines, more preventive maintenance performed. This relationship is explained by the fact that a machine with many components have more probability to have small problems or a slowing down.

Also the maintenance members, who check constantly the machines during ordinary interventions following the upkeep planning, schedule also some preventive maintenance. Planned maintenance has also the scope of monitoring any decay of the machine. This is why the number of planned maintenance activities per year and the number of ordinary upkeep activities performed in the previous year are strictly related with the detection of problems and successively the intervention before the breakdown. These activities can be planned with the responsible of production during not saturated periods to reduce the impact of the stop.

The model also shows that there is a correlation between the level of automation of the machine and the number of preventive maintenance performed. In particular, the machines that require less the presence of employees have a lower number of preventive activities. This can be explained by two reasons: first of all automatic machines have less operators so it is difficult for them to observe errors or problems. In particular, in the moulding department there are only two operators dedicated to twenty machines. Secondly, automatic machines are more complex so components are protected with crankcases. These protective devices on average reduce the transparency of movements' parts and inevitably the possibility for operators to see.

	equipmer	nofworke	workerage	hoursofpr	nofmachir	Equipmen	Impactonl	Yearsofex	nofworke	Automatic	Utilizatio	avgnofset	AVGtimep	nofproduc	nofmainte	plannedm	Nofordina	autonomc	ordinarym
Mean time to repair	0.0848	-0.0219	-0.2771	0.0631	0.0655	-0.0432	0.1027	-0.3100*	0.0339	0.0747	0.2299	-0.0097	0.1212	-0.0502	0.0522	0.0250	-0.0242	0.1123	-0.1086
OEE	-0.1685	0.0516	0.1056	-0.4328*	-0.1724	-0.2271	-0.2776	-0.0099	-0.0846	0.0100	-0.3253*	-0.1814	-0.2595	-0.1360	0.0108	0.0700	-0.1736	-0.3400*	-0.4271*
n° of downtime/extraordina	0.1008	0.0459	-0.0939	0.1273	0.1228	-0.0921	-0.0655	0.0876	0.1482	0.0743	-0.0214	-0.1306	-0.0127	-0.1450	0.0759	0.0534	0.0193	0.2058	-0.0388
mean time for intervention	0.1323	-0.0188	-0.2234	0.1125	0.1615	0.2089	0.3754*	-0.1662	-0.2019	0.0489	0.2553	0.1071	0.3486*	0.0767	0.1624	0.0356	0.2481	0.2802	0.3863*
mean time between failure	-0.2261	-0.2250	0.1249	-0.0332	-0.2062	-0.0292	0.1131	0.0669	-0.2582	0.1071	-0.2368	-0.1440	0.0608	-0.1585	-0.1362	-0.1941	-0.1832	-0.1060	-0.0231
Activities of improvement	-0.1926	0.0589	0.1042	-0.2479	-0.1377	0.0802	-0.0741	-0.0406	-0.0814	-0.2471	0.0346	0.2310	-0.0845	0.1808	-0.0103	0.0194	0.1158	-0.1998	0.1726
Hours of maintenance (only	-0.1411	0.0103	-0.0976	0.0353	0.0522	0.1595	0.1235	-0.1021	-0.0379	-0.1230	0.2781	0.2600	0.1717	0.1712	0.1368	0.0670	0.2759	0.1186	0.3629*
of which improvements	0.1563	0.1657	0.3370*	-0.4383*	-0.1472	-0.0238	-0.2548	0.0255	-0.1784	-0.2364	-0.3889*	0.0069	-0.3883*	0.1411	0.0384	0.2168	0.0352	-0.3895*	-0.2669
of which ordinary	0.0924	-0.1955	-0.3422*	0.2068	-0.0859	-0.1601	0.1504	-0.1872	0.0065	0.2770	0.1770	-0.0810	0.2006	-0.0626	-0.0284	-0.0046	-0.0530	0.1881	-0.1024
of which extraordinary	-0.0622	0.0446	-0.1456	0.1469	0.1602	-0.0248	0.0563	0.1063	0.2766	0.0071	0.3894*	0.0305	0.1436	-0.0686	0.0061	-0.0998	0.0138	0.1819	0.1408
n° of preventive maintenan	-0.0448	0.4794*	0.1601	-0.3061*	0.7661*	0.6602*	-0.2670	-0.0205	0.1364	-0.4061*	0.0219	0.4831*	-0.1626	0.5315*	0.8977*	0.7838*	0.8401*	-0.2651	0.3818*
hours of preventive mainte	-0.1253	0.3297*	0.1922	-0.3665*	0.6312*	0.4971*	-0.1605	0.0191	0.0215	-0.2402	0.0456	0.3247*	-0.0497	0.3615*	0.9160*	0.7312*	0.7784*	-0.2160	0.3024*

Figure 35: The area of correlations

	equipmentage	nofworkers~t	workerag	hoursofpr	nofmachine~n	Equipmentd~n	Impactonl	Yearsofexp	nofworke	Automati	Utilizatio	avgnofset	AVGtimep	nofprodu
equipment age	10.000													
n° of workers per shift	0.1779	10.000												
worker age	0.0377	0.2663	10.000											
hours of production	0.3909*	-0.2677	-0.3191*	10.000										
n° of machines involved (affecting c	0.1938	0.7697*	0.0994	0.0201	10.000									
Equipment dimension	0.2058	0.7187*	0.2112	0.0058	0.8955*	10.000								
Impact on health (difficoltà ad inter	-0.1869	-0.6331*	-0.2088	0.3895*	-0.3720*	-0.3819*	10.000							
Years of experience of workers	-0.0041	0.1674	0.7620*	-0.0793	0.0210	0.0280	-0.0253	10.000						
n° of workers within the team	0.3071*	0.4381*	-0.0918	0.1690	0.4276*	0.3276*	-0.7070*	-0.0092	10.000					
Automatic/manual	-0.1960	-0.8744*	-0.2846	0.3302*	-0.6028*	-0.6577*	0.7666*	-0.1338	-0.5302*	10.000				
Utilization rate	-0.0886	-0.1362	-0.2807	0.4091*	0.1102	-0.0857	0.3771*	0.0529	0.2259	0.2111	10.000			
avg n° of setups x month	0.1008	0.8014*	0.0237	0.0216	0.8103*	0.8420*	-0.5303*	-0.0882	0.5619*	-0.6998*	0.1080	10.000		
AVG time per setup	-0.2413	-0.6028*	-0.3464*	0.4555*	-0.2217	-0.2169	0.8403*	-0.1692	-0.4598*	0.7820*	0.4422*	-0.2716	10.000	
n° of products managed/produced	0.1592	0.8679*	0.0951	-0.0986	0.8534*	0.8313*	-0.5636*	-0.0272	0.4764*	-0.7195*	-0.0123	0.9684*	-0.4206*	10.000
n° of maintenance activities (conteg	-0.1302	0.4238*	0.0524	-0.3281*	0.7338*	0.5892*	-0.1887	-0.1142	0.0275	-0.2749	0.0538	0.4667*	-0.0762	0.5865*
planned maintenance activities per	-0.0022	0.5340*	0.0717	-0.3227*	0.6996*	0.5641*	-0.3443*	-0.0962	0.0751	-0.3749*	-0.0264	0.5129*	-0.2917*	0.7585*
N° of ordinary maintenance done	-0.0558	0.6329*	0.0886	-0.2725	0.8226*	0.7469*	-0.2798	-0.0743	0.0774	-0.4531*	-0.0220	0.6691*	-0.1664	0.8056*
autonomous maintenance done	0.0515	-0.2875*	-0.1494	0.6302*	-0.1420	-0.1272	0.6413*	0.0413	-0.2008	0.4799*	0.3905*	-0.1026	0.6603*	-0.3372*
% ordinary maintenance done in 20:	-0.0774	0.5567*	0.0614	-0.0402	0.5811*	0.6954*	-0.1353	0.0011	0.1159	-0.4417*	-0.1275	0.6443*	0.0434	0.5192*
Mean time to repair	0.0848	-0.0219	-0.2771	0.0631	0.0655	-0.0432	0.1027	-0.3100*	0.0339	0.0747	0.2299	-0.0097	0.1212	-0.0502
OEE	-0.1685	0.0516	0.1056	-0.4328*	-0.1724	-0.2271	-0.2776	-0.0099	-0.0846	0.0100	-0.3253*	-0.1814	-0.2595	-0.1360
n° of downtime/extraordinary main	0.1008	0.0459	-0.0939	0.1273	0.1228	-0.0921	-0.0655	0.0876	0.1482	0.0743	-0.0214	-0.1306	-0.0127	-0.1450
mean time for intervention	0.1323	-0.0188	-0.2234	0.1125	0.1615	0.2089	0.3754*	-0.1662	-0.2019	0.0489	0.2553	0.1071	0.3486*	0.0767
mean time between failures	-0.2261	-0.2250	0.1249	-0.0332	-0.2062	-0.0292	0.1131	0.0669	-0.2582	0.1071	-0.2368	-0.1440	0.0608	-0.1585
Activities of improvement	-0.1926	0.0589	0.1042	-0.2479	-0.1377	0.0802	-0.0741	-0.0406	-0.0814	-0.2471	0.0346	0.2310	-0.0845	0.1808
Hours of maintenance (only interna	-0.1411	0.0103	-0.0976	0.0353	0.0522	0.1595	0.1235	-0.1021	-0.0379	-0.1230	0.2781	0.2600	0.1717	0.1712
of which improvements	0.1563	0.1657	0.3370*	-0.4383*	-0.1472	-0.0238	-0.2548	0.0255	-0.1784	-0.2364	-0.3889*	0.0069	-0.3883*	0.1411
of which ordinary	0.0924	-0.1955	-0.3422*	0.2068	-0.0859	-0.1601	0.1504	-0.1872	0.0065	0.2770	0.1770	-0.0810	0.2006	-0.0626
of which extraordinary	-0.0622	0.0446	-0.1456	0.1469	0.1602	-0.0248	0.0563	0.1063	0.2766	0.0071	0.3894*	0.0305	0.1436	-0.0686
n° of preventive maintenance done	-0.0448	0.4794*	0.1601	-0.3061*	0.7661*	0.6602*	-0.2670	-0.0205	0.1364	-0.4061*	0.0219	0.4831*	-0.1626	0.5315*
hours of preventive maintenance	-0.1253	0.3297*	0.1922	-0.3665*	0.6312*	0.4971*	-0.1605	0.0191	0.0215	-0.2402	0.0456	0.3247*	-0.0497	0.3615*

	nofmainte	plannedm	Nofordina	autonomo	ordinarym	Meantime	OEE	nofdownt	meantime	meantime	Activities	Hoursofm	ofwhichin	ofwhichor	ofwhichex	nofprever	hprevmai
n° of maintenance activities (conteg	10.000																
planned maintenance activities per	0.8966*	10.000															
N° of ordinary maintenance done	0.9074*	0.9030*	10.000														
autonomous maintenance done	-0.3219*	-0.4323*	-0.2472	10.000													
% ordinary maintenance done in 20:	0.3173*	0.1674	0.5575*	0.1940	10.000												
Mean time to repair	0.0522	0.0250	-0.0242	0.1123	-0.1086	10.000											
OEE	0.0108	0.0700	-0.1736	-0.3400*	-0.4271*	0.1713	10.000										
n° of downtime/extraordinary main	0.0759	0.0534	0.0193	0.2058	-0.0388	0.2419	0.2468	10.000									
mean time for intervention	0.1624	0.0356	0.2481	0.2802	0.3863*	0.4115*	-0.6483*	-0.2253	10.000								
mean time between failures	-0.1362	-0.1941	-0.1832	-0.1060	-0.0231	-0.4953*	0.0428	-0.4713*	-0.2056	10.000							
Activities of improvement	-0.0103	0.0194	0.1158	-0.1998	0.1726	-0.2245	-0.3832*	-0.6714*	0.3032*	0.1341	10.000						
Hours of maintenance (only interna	0.1368	0.0670	0.2759	0.1186	0.3629*	-0.0037	-0.7016*	-0.2856*	0.6166*	-0.1834	0.7759*	10.000					
of which improvements	0.0384	0.2168	0.0352	-0.3895*	-0.2669	-0.1694	0.3540*	-0.3691*	-0.1538	0.2238	0.4142*	-0.0465	10.000				
of which ordinary	-0.0284	-0.0046	-0.0530	0.1881	-0.1024	-0.0245	-0.0766	-0.0777	0.1511	0.0611	-0.0986	-0.0395	-0.2205	10.000			
of which extraordinary	0.0061	-0.0998	0.0138	0.1819	0.1408	0.4879*	-0.2139	0.4811*	0.2420	-0.6907*	-0.2486	0.1732	-0.6755*	-0.1609	10.000		
n° of preventive maintenance done	0.8977*	0.7838*	0.8401*	-0.2651	0.3818*	0.0948	-0.0244	0.2534	0.1751	-0.1866	-0.0482	0.1817	0.0054	-0.1428	0.1011	10.000	
hours of preventive maintenance	0.9160*	0.7312*	0.7784*	-0.2160	0.3024*	0.0882	0.0307	0.2537	0.1632	-0.1798	-0.0505	0.1693	0.0105	-0.1217	0.1073	0.9434*	10.000

Figure 36: Correlation matrix of independent and dependent variables

Conclusions

Considering the fact that "*there is no single correct method for the implementation of a TPM programme*" (Wireman T., 1991), there is a unanimous creed about the difficulty of implementation. In 1988, Nakajima analysed twelve steps of TPM development, considering that the lean approach at that year was in the start-up phase. Complexity is given by the idea of a total involvement of employees within the firm, therefore many restraining forces to manage. As explained by Nasurdin A. M. et al. (2005) TPM has a deep influence on job characteristics, therefore there is the risk of coming back to the *status quo* due to individual resistance to change. This obstruction is proposed by Attri R. et al- (2014), who show that there are five groups of potential barriers to overcome: behavioural, human, strategic, operational and technical.

For the firms that are able to implement TPM, achieving small results in the short term is fundamental for future development. Even if this approach is oriented to the long term, this thesis shows that small improvements are achievable in some months. The positive point of this study is the realization of satisfactory results in five month after the implementation. Improved KPIs are fundamental in the process of settling and standardizing the new approach because they increase the motivation within employees that the street undertaken is the right one. Although the implementation has been facilitated by a complex and structured maintenance plan previously developed, TPM has surely affected positively OEE, mean time between failures and time spent for extraordinary activities.

However, these results are influenced by many contextual factors that has to be considered. The study proposed by Mckone K. E. et al. (1999) shows the impact of environmental, organizational and managerial context on TPM; particularly on planned and autonomous maintenance, comparing 97 different manufacturing plants Nevertheless, what about operative factors within the same firm? Which variables affect KPIs?

Answering these questions, the model analysed shows how variability has influenced positively or negatively the results achieved. The contextual factors that have an impact on the TPM realization can be divided into two categories: operative and technical based variables.

The operative factors that influence the most the indicators of performance are hours of production and utilization rate. Indeed, the machines utilized the most are which report lower results due to lower OEE enhancement, because each intervention (planned upkeep or activity of improvement) has to be performed stopping the machine. Furthermore, high utilization rate increase the possibility of critical breakdowns that have to be fixed in an accurate manner. In addition, a complex maintenance schedule already implemented reduces substantially the improvements in terms of KPIs but is essential to create a deep knowledge of the machine, both for operators (autonomous maintenance) and the maintenance team. This knowledge has to be utilized in the creation of a meticulous preventive maintenance programme.

Machines’ characteristics have not a high impact on KPIs’ results however, they are fundamental for the preventive maintenance approach. Machines that are automatic, dedicated to one or a little number of products (low number of setups) and standalone equipment in the short term have lower development of preventive activities. Unexpectedly, equipment’s age does not affect performance. Therefore, operators have to manage older machines with the same dedication of the others.

In conclusion, this paper has demonstrated a strong relationship among TPM and operative factors trying to give a rational motivation for the most significant variables. Clearly, the model analysed is not universal, both for the variables analysed and for the TPM program implemented, which is strongly linked to the management of the firm, however it gives an identification of the best-suited conditions for achieving better results in the short term, which are essential for a complete TPM development.

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