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# Basics of Maintenance Engineering



**MAINTENANCE**

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# BASICS OF MAINTENANCE ENGINEERING



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# Introduction

In the last years and in the last centuries maintenance has undergone a complex evolution. Since ancient times people have been trying to make tools, equipments and machines with a better quality, efficiency and reliability. [1]

In the 20<sup>th</sup> and 21<sup>st</sup> centuries when the military industry and other industrial members use more and more precise and complex machines, production lines and processes, maintenance and the continuous improvement are achieving a higher level than ever. [1]

This book provides an overview of the development and evolution of the maintenance and the most important tools of maintenance engineering. The reader can get basic information about the definition and importance of 'just in time' and different types of maintenance strategies and triggers, which are the most important parts of a modern industrial environment nowadays (2017). One can find these definitions in the everyday life of a modern lean factory. [1]

The book describes the importance of the maintenance, triggers and key performance indicators in practice. The lean tools contain the most popular tools and methods for modern maintenance teams and engineers. The key performance indicators, such as OEE<sup>1</sup> and the method of root cause analysis help maintenance team to solve different technical or maintenance problems in the daily routine. The modern lean manufacturing principles increased the importance of maintenance and operation. [1]

The book contains 25 chapters and several sub-chapters. The chapter before the last contains different case studies from industrial field, these case studies come from the following areas: 5S, TPM and FMEA.<sup>2</sup> These case studies can be help to the engineers of the future to implement and improve their skills and methods in the practice. The book will give guidance on the possibilities of new maintenance methods, which are based on lean techniques and philosophy. [1]

The main purpose of this book on Maintenance Engineering is to introduce the main definitions and tools for the international trends and brands. I hope students and engineers will use this book with satisfaction during their study or work. [1]

<sup>1</sup> Overall Equipments Effectiveness

<sup>2</sup> Failure Mode and Effect Analysis

# 1. History of Maintenance

## 1.1 Theoretical background of maintenance

Since the beginning of the human history, engineers, workers and operators have always felt the need for the maintenance of their equipment and machines. Most of the failures experienced have been a result of abuse, as it sometimes still happens. These people would do maintenance only when the machines were no longer possible to use. The name of this strategy is: Breakdown or Reactive Maintenance. The reader can get more details about it later. [1-16]

In the early period of the maintenance the engineers found a very important field of maintenance: lubrication. The engineers in the ancient times tried to develop lubrication equipment and processes. They used time cycle check to investigate the failures as a result of bad lubrication. These engineering works date back to the Ancient Egypt. In the Greek and Roman cultures, the military equipments get an important role in daily life and politics. These cultures built a lot of battering, ship, mangonel catapults etc. They made a lot of notes about technical inspections, maintenance steps and reconstructions about these machines. [1-16]

Leonardo da Vinci was the first scientist or engineer who started to investigate structural materials. Thanks to these experiments he could build machines with a higher safety and with better operation properties. Da Vinci continuously developed his earlier machines. [1-16]

During the industrial revolution a lot of new machines came out of the factories. These machines were very complicated, they contained many machine parts and/or liquids. These reasons created the basis of the maintenance plans and processes. In the Steam-Engine period the machine operation was more important than the installation technology. The machine operators were not only simple workers. They were the maintenance team as well. These kinds of machine operators had high skills for maintenance processes and they were highly qualified. In these times the technical reliability was poor. It was the time of the foundation of maintenance plans and concepts. [1-16]

After the industrial revolution the structural materials underwent a lot of changes. Researchers and engineers found new ways of production. The new production processes and new raw materials had an effect on maintenance. In the area of military technology, we can find a lot of maintenance strategies in 19th century. These strategies generated a dynamic and continuous improvement in the history of maintenance. But the most important thing that one can find in the 19<sup>th</sup> century

maintenance strategies is the appearance of customer demand. In the 21<sup>st</sup> century, maintenance is an integral part of the quality assurance systems of different companies. [1-16]

Much has happened in engineering life since the industrial revolution, but perhaps the most dramatic and important changes have occurred in the last sixty and seventy years. These changes have of course affected how an industrial plant has been maintained in everyday life. [1-16]

Prior to the Second World War machinery was generally quite rugged and relatively slow running and worked with a such a high inaccuracy; instrumentation and control systems were very basic or often not in use. The demands of production were not overly severe so that downtime was not usually a critical issue and it was adequate to maintain machines on a breakdown basis. The machinery was inherently reliable. Important to know, nowadays the factories have to pay to each other if they make any failures in the supply chain or in the other factory production. [1-16]

From the beginning of the 1950's with the rebuilding of industry after the second world war, particularly that of Japan, there were developed a much more competitive marketplace; there grew an increasing intolerance towards downtime and machine failures. The cost of labour became increasingly significant, leading to more and more mechanization and automation. Machinery was of lighter construction and ran at higher speeds and the accuracy became better. Production demanded better maintenance than before, which led to the development of Planned Preventative Maintenance. From the 1970's a lot new economic conditions appeared. A lot of new and complicated machines entered the markets. In these years the engineers started to use diagnostic equipment. [1-16]

Ten years later the new world order created a new competition on the marketplace. This competition resulted in a better and stronger needs for excellence in all procedures. The new standards created a dozen of maintenance strategies and tools, which proved to be more dynamic systems than ever before. One of the most important methods is the Total Productive Maintenance (TPM). The TPM is based on continuous improvement. In TPM systems everyone in the organization has to be optimizing the maintenance processes, tools and machines. These improvements result in a better efficiency of the machines. [1-16]

This new philosophy has a brand-new approach. It means that the new methods will be always up to date. This is what we call continuous improvement in the practice. In the later chapters the reader can find more details about these techniques. In the daily life the engineers use two different names of TPM: Total Productive Maintenance or Total Participation Maintenance. [1-16]

The purpose of maintenance is to transform the attitude of all the members of the industrial community: all kinds and levels of workers, operators, supervisors, engineers, administrators are involved in this major responsibility. The employees have to understand to improve their processes, tools and they have to develop their knowledge and skills. The TPM implementation is a very difficult goal. This method make a lot of benefits, but we should also know about its various disadvantages. It can make a lot of misunderstanding in the organization. But in long terms the TPM can make more productive and safer machines with better efficiency and products with a better quality. In the modern industrial environment all of the employees are responsible for the quality. In the 21<sup>st</sup> century the most important maintenance tool is the TPM. Next to the TPM we can find a brand-new definition what we call Industry 4.0. In a lot of articles and books we can find it defined as the new industrial revolution. The IT techniques and equipment get more significant on the maintenance field. This is the new era of the modern maintenance engineering. [1-16]

## 1.2 Pioneers of Maintenance and Management

The most important researchers of scientific management (in the 1900's) were Frank Bunker Gilbreth (Figure 1.) and his wife Lillian Moller Gilbreth. They were the pioneers of the modern scientific management, they had done a lot of research on time and motion. Frank B. Gilbreth is perhaps best known as the father and central figure of Cheaper by Dozen. Lillian Moller Gilbreth was the first engineer who had a PhD degree. [2]



*Figure 1.: Frank B. Gilbreth with his wife (facing the camera) [17]*

Henry Gantt was an American mechanical engineer and engineering consultant who created a Gantt chart in the 1910's and started the selection of the operators with scientific tools. Henry Gantt had other important projects and works in the past not only on the Gantt chart (Figure 2.) He had a lot of study on Industrial Efficiency and on Task and Bonus System, which are very important and popular tools in a modern factory. [2]



Figure 2.: Gantt chart [18]

Until the end of the 1930's we can find a lot of new management methods and tools but after these years the speed of the improvements are slowing down. [2]

Thanks to the new era of the management philosophy the industry got a big aid. We can find a lot of new methods in practice like 5S<sup>3</sup> and TQM (Total Quality Management). The TQM uses a stronger people knowledge and experience in Kaizen projects and Just in Time principles. These points are shown in Figure 3. [2]

<sup>3</sup> Lean methodology

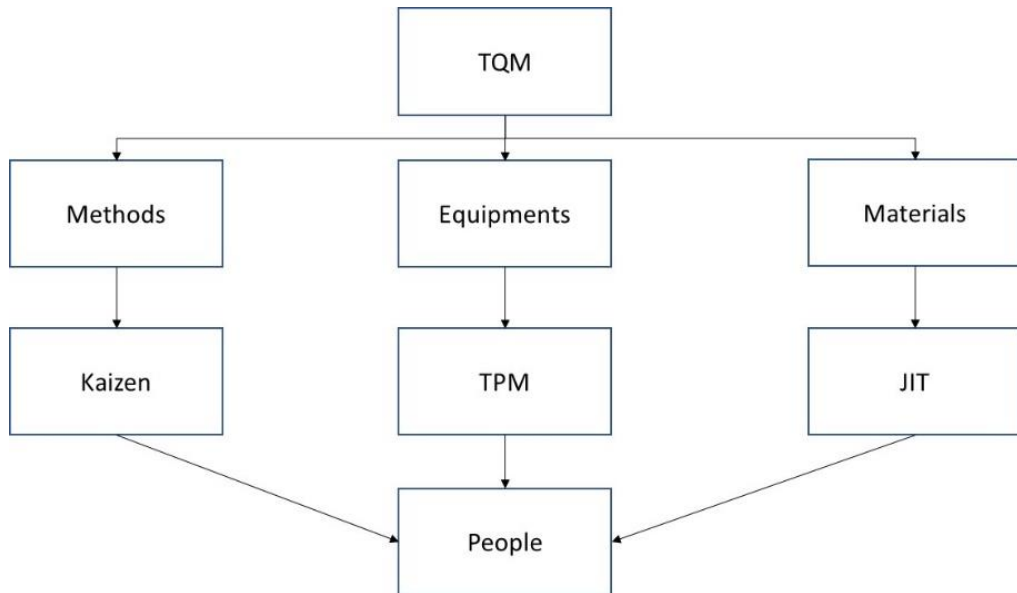


Figure 3.: TQM and Lean tools relationship [2]

Beside the TPM<sup>4</sup> we can find two other methods. These are the Computerized Maintenance Management System (CMMS) and the Reliability Centered Maintenance (RCM). Figure 4. shows the evolution of maintenance until 1990. [2]

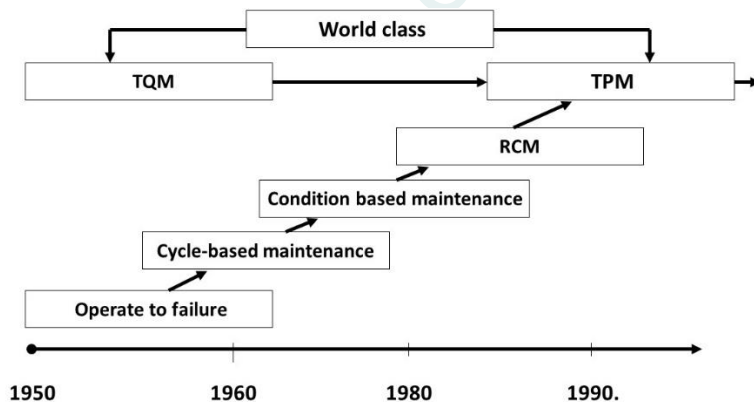


Figure 4.: The evolution of maintenance until 1990 [2]

## 2. Maintenance Strategies

### 2.1 What is Run-to-Failure maintenance (RTF) – Reactive Maintenance

The run – to - failure maintenance is the simplest maintenance strategy we know, and this is the oldest strategy. In the literature, we can find it as run-to-fail method or strategy. In this strategy,

<sup>4</sup> Total Productive Maintenance

assets are deliberately allowed to operate until they break down, at which point reactive maintenance is performed. After the breakdown, the maintenance team must start to perform a reactive maintenance. During this strategy no other maintenance method is being used. In modern industries, the companies try to avoid this kind of maintenance approach, because the industrial processes are very sensitive to unexpected failures. [19]

Under the run – to - fail maintenance, it is very important to have safety stock from the failed parts. It means that, the company has to operate a logistic system to control the maintenance process, which means that they have to buy machine parts. This strategy should not be confused with reactive maintenance, because of the active plan to allow the asset to run – to - failure. This strategy can be useful when the machine elements have no safety risk and they have a minimal or no effect on production, customer demand and the supply chain. [19]

The easiest example for run-to-failure process is the maintenance or the change of a light bulb. We switch on the light and the bulb is allowed to run. It can run until it fails. At this time we can or we have to fix this problem (because we do not want to sit in the dark room). We can get a new bulb from the stock (or from our garage) and replace the old one. [19]

Advantages [19]:

- Minimal planning need, the production planners do not have to schedule the loss of time from the production, maintenance is needed when any breakdown or failures happened (it is stressful to the maintenance team)
- Easy to implement in practice, it is easy to understand, and nobody have to make decisions about the machine condition, it just runs until fails – but sometimes it is not a benefit

Disadvantages [19]:

- Unpredictable – Because most asset failures are unpredictable, it is difficult to anticipate when manpower and parts will be needed for repairs
- It is difficult to plan ahead, these kinds of failures are not meet the customer demand and production processes, in this case it is difficult to plan with human resources and other tools.
- Inconsistent
- It has high costs - all of the costs have to be considered during the budget planning, this strategy contains a lot of hidden costs, unplanned failures etc., the factory management have to plan with quality complaint costs as well as with failed customer demands

- Inventory costs (see „7 wastes” later) – The maintenance team needs to hold spare parts in a safety inventory, to adjust for infrequent failures

The unplanned/reactive maintenance method is the only approach of maintenance used for the run-to-failure maintenance strategy. In practice we know and use some maintenance triggers (the reader finds a chapter about maintenance triggers). In run-to-failure maintenance strategy we know only one trigger, it is the asset break-down. It is very easy to use and understand: „*If the asset is not working, then the maintenance is required.*” [19]

In the previous paragraphs we saw the advantages and disadvantages of run-to-failure maintenance strategy. This strategy makes sense when the total maintenance cost of repair after break-down is less than the cost of performing other types of maintenance on the equipment beforehand. For example, if we have a machine, that works in continuous production shifts (24/7). We are shutting it down every month to make the maintenance steps, it can create the same disruption as if we just let it break down, what can happen 1 or maximum 2 times in a year. In this case, it makes sense to simply repair it when it breaks! It is very important during the maintenance to find the reasons for every machine breakdown and find, analyze and understand the consequences about the failures. [19]

Run-to-failure maintenance cannot be used in a lot of fields. Especially where the breakdowns and failures cause safety risk, for example elevators, brake systems or medical industry etc. Missing maintenance steps or processes can be dangerous for human life and health and companies can lose a lot of money. [19]

After understanding the theoretical background, the second step is the initiation of the run-to-failure maintenance strategy. The RTF can work from human memory (especially at small companies). But standards and customers demand a paper-based maintenance systems or Computerized Maintenance Management System (CMMS). The question is: which is better, a CMMS or a simple paper-based maintenance strategy? It is depending on the size of the company. A CMMS system can provide more ways than needed for a small company. Thanks to the CMMS and any other IT solutions different types of maintenance methods and strategies can work at the same time or parallel to each other. It is a requirement for a flexible organization. CMMS system can show a lot of useful information about the repaired machine elements and costs. Thanks to CMMS maintenance costs can be planned. But never forget the big safety stock of the new machine parts! [19]

## 2.2 Periodic Maintenance

The periodic maintenance is a big step in the evolution of maintenance strategies. It is a scheduled maintenance method of pieces of equipment. In this case the maintenance engineers have to prolong the years of the machine parts usage. During the periodic maintenance, it is important to make maintenance notes about the repaired machine or machine parts. In ISO systems we can find details about the maintenance records. It can be very important, especially in vehicle industry or aircraft industry where various accidents can happen from insufficient maintenance. [20]

In practice we know six main steps of periodic maintenance, these are the following [20]:

- Cleaning
- Dusting
- Washing
- Oiling
- Adjusting selected parts
- Replacing faulty parts

The periodic maintenance has a lot of practical advantages. This method helps to save or increase the life time of the machines and tools. It can save costs and energy if it is well planned. It can highlight knowledge and experience for the organizations maintenance team. [20]

## 2.3 Preventive Maintenance

Preventive maintenance can be defined as follows: *“Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level.”* [21]

The equipment designer defined the maintenance activities, which can increase the reliability and extend the lifetime of the equipment. The organization can save money if it uses preventive maintenance. Studies and articles show the measure of this cost efficiency. In different industrial areas we can find 12% to 18% on average. [21] [22]

Advantages [21] [22]:

- Cost effective not only in the maintenance process, we can also find the effect of the periodic maintenance for example in supply chain management
- It has a high flexibility, it can allow for a reschedule of the maintenance steps

- Increased machine elements life time
- It can save energy
- Reduced equipment or process failures
- Estimated 12% to 18% cost savings
- Less stress for the organization

Disadvantages [21] [22]:

- Catastrophic failures still possible to occur, due to incorrect schedule
- Labor intensive: schedule, human resources, tools etc.
- Includes performance of unneeded maintenance, sometimes machine parts are working well over the maintenance period
- Potential for incidental damage to components in conducting unneeded maintenance

Good to know: the preventive maintenance strategy is not an ideal maintenance program. It has many advantages but, in the practice, it is not so cost effective in every case. Some preventive maintenance steps make a better efficiency run for the equipment. It leads to a better product quality too. During this maintenance strategy the maintenance team cannot prevent all the failures, but they try to decrease the quantity of the breakdowns. To prevent the failures, the maintenance team have to use other methods - what we called predictive maintenance strategy. [21] [22]

## 2.4 Predictive Maintenance

The predictive maintenance is an important point of maintenance systems. The reader has to understand the explanation of this kind of maintenance method. Under the predictive maintenance different types of measurements are used. These measurements can show the actual technical status or physical state of the machine, machine elements or the different lubricants and working fluids. [23]

The measured results can show the status of the current and the future state. The differences between the predictive and preventive maintenances is clear and easy to understand. The preventive maintenance is based on a plan, while the predictive maintenance depends on the actual condition of the machines. [23]

Some activities are based on time. This time can be calendar or equipment run time (for example maintenance at cars). The simplest example is the lubricant change in cars. The drivers have to change oil every 20,000 km or after one year in a Diesel engine (Volvo, D2, D4162T). We can see two numbers, the run time of the vehicle and a date. These numbers define the oil change period.

This system has a special feature, i.e. it does not care about the condition of the oil. It is changed because it is time to. These sentences make it clear that the predictive maintenance shows similar properties to the preventive maintenance. But if the owner analyzed the condition of the oil with the service station or with a mechanic, he can use the parameter deviation. For example, the car can run more than 20,000 km or use the oil for more than 1 year. This difference is the most important thing that can show the essential difference between the preventive and predictive maintenance strategies. [23]

Advantages [23]:

- Increases the availability of machines, machine elements and tools
- Allows for preventive actions
- Decreases the machines, machine elements and tools downtime
- Decreases costs for parts and labor
- It can contribute to better product quality
- Improves the maintenance team knowledge and the maintenance know-how of the company
- Energy savings
- Cost savings on a long term

Disadvantages [23]:

- High investment costs, expensive diagnostic equipment
- Expensive training costs
- Not easy to show the cost effectiveness for the management. First, the predictive maintenance need a high investment and only later one can see the efficiency of this kind of maintenance strategy

Easy to see that a well scheduled predictive maintenance method can eliminate most of the machine failures. The management can calculate with the overtime and any other maintenance costs. With this recalculation the engineers are able to minimize the stock levels. The engineer can develop and increase the efficiency of the machines, save energy and the machines can make products with better quality. Numerous studies and scientific works show the effectiveness of the predictive maintenance. The companies can reach 6%-12% savings with predictive maintenance in the practice. [23]

## 2.5 Reliability Centered Maintenance

The reliability centered maintenance (RCM) made a big breakthrough in the maintenance evolution. This maintenance nothing else but a process which can help to define the maintenance requirements of a machine or machine element in its operating environment. [24] [25]

The reliability maintenance methods work with new approaches and points of view. It means the following: this point of view says that not all of the machines have the same priority on the shopfloor. Several machines are less important from the customer side than others, while some of them are the "bottle neck(s)" in the company. The bottle neck is the weakest point of the factory. If any failure happened with these machines the whole factory can be shut down or it can even damage the safety of the facility. The RCM takes into account the design and operation differences between the machines. It accounts for differences in operation conditions and failures. The RCM philosophy can recognize the fact that the financial and human resources differ between the companies. These facts emphasize the importance of the optimized and good prioritized processes. This method tries to investigate the best way to use the equipment, processes and human resources in the daily maintenance life, in parallel with the best cost effectiveness. The reliability maintenance is dependent on the predictive maintenance. [24] [25]

Advantages [24] [25]:

- RCM can be the most efficient maintenance program with the right know-how
- Lower costs
- Minimizes frequency of repairing
- Reduces probability of sudden breakdowns
- Able to focus on maintenance activities on critical/main components and machines
- Increased component reliability and efficiency
- Incorporates root cause analysis, it can improve the organization and maintenance processes

Disadvantages [24] [25]:

- High cost during the first step of implementation (diagnostic equipment, trainings etc.)
- Cost effectiveness is not clear to the management

## 2.6 Condition Based Maintenance – CBM

The condition base maintenance (CBM) is a special maintenance method. This strategy monitors the condition of the machines and machine elements and it can decide which is the most optimal maintenance need for the task. The CBM shows the ideal point to start the operation. Many maintenance indicators help to show this kind of intervention points. These kinds of indicators are non-invasive measurements, for example: visual inspections, performance data and scheduled tests. The condition data can be collected continuously or at certain intervals. Good to know: some machines have internal sensors, but engineers can develop new sensor systems to collect information and data about the status of the machine. Condition based maintenance can be applied to both critical operation and non-critical machines. [26] [27]

The planned or the scheduled maintenance is based on scheduled maintenance steps, while the condition based maintenance works in its own way. The condition based maintenance is performed only when the system can find a degradation in the condition of the machine parts. The CBM increases the time between the maintenance steps if it is compared with preventive maintenance. This fact shows that the production gets a wider gap to continue. [26] [27]

Advantages [26] [27]:

- CBM is performed while the asset is working, this lowers disruption of normal operations
- CBM is used during the operation of the machine, thus it can decrease the deviation in the normal operation
- Reduces the cost of failures
- Improves equipment reliability and efficiency
- Minimizes unscheduled downtime and catastrophic failures
- Minimizes time spent on maintenance
- Minimizes overtime costs by scheduling the activities
- Minimizes the safety stock levels of the machine parts or maybe it can eliminate it
- Optimized maintenance intervals can be more optimal than manufacturer recommendations or what is in the machine documentation
- Improves safety
- Reduces the chances of collateral damage to the system

Disadvantages [26] [27]:

The CBM has a high implementation cost: the condition monitoring hardware and software are expensive. [26] [27]

- High costs of employee trainings
- Difficult to find fatigue or uniform wear failures
- The condition sensors can be sensitive to the operating environment (noise, heat, vibration etc.)
- May require modifications to „retrofit” the system with sensors
- Unpredictable maintenance periods

In the practice we know the following types of condition based maintenance [26] [27]:

- Vibration analysis: rotating equipment such as compressors, pumps, motors all exhibit a certain degree of vibration. As they degrade, or fall out of alignment, the intensity of vibration increases. Vibration sensors can be used to detect when this becomes excessive.
- Infrared: IR cameras can be used to detect high temperature conditions in energized equipment
- Ultrasonic: detection of deep subsurface defects such as boat hull corrosion
- Acoustic: used to detect gas, liquid or vacuum leaks
- Oil analysis: measure the number and size of particles in a sample to determine asset wear
- Electrical: motor current readings using clamp on ammeters
- Operational performance: sensors throughout a system to measure pressure, temperature, flow etc.

## 2.7 Risk-Based Maintenance

The Risk-Based Maintenance (RBM) puts the focus on the riskiest machine parts. This method determines the most economical use of maintenance and human resources. It can work in a facility if the maintenance effort is optimized to minimize all of the risk of any failures. [28]

A Risk-Based Maintenance strategy is based on two main phases [28]:

- Risk assessment
- Maintenance planning based on the risk

The whole maintenance strategy is based on the risk(s) of the failure(s). This simple rule defines the type and the frequency of the maintenance. The whole system checks the critical failures with

a high precision. The machines with lower risks get less stringent maintenance programs. The Risk-Based Maintenance strategy creates a system with the lowest failures and the highest efficiency. [28]

The machines with high risk in the most case get condition based maintenance programs. [28]

## 2.8 Total Productive Maintenance – TPM

The Total Productive Maintenance (TPM) nowadays is the most important and popular maintenance technique all around the World. It is not only a strategy or a method, it is a complex philosophy which requires the work of the whole organization, like machine operators, maintenance engineers, quality engineers or tool engineers etc. TPM uses the knowledge and experience from the employees and keep the focus on the continuous improvement, product quality and machine efficiency. The total productive maintenance concept can be mainly found in production areas, but nowadays it exists in office areas (e.g. National Instrument Hungary Ltd., Hungary, Debrecen, Green Tag TPM system). [29]

The TPM follows all of the production aspects - it is the base of the TPM system. The maintenance factor is one of the most important indicators of the production. The management measures the TPM activity, the most useful measurement indicator is the Overall Equipment Effectiveness (OEE) number. It is a measure of availability, performance efficiency and quality rate. [29]

These short paragraphs above contain some details about TPM philosophy. The reader gets a deeper knowledge about these maintenance and lean tools in another chapter. [29]

## 2.9 Value Driven Maintenance -VDM

The maintenance is one of the most important departments in any companies. The machines and tools cannot work with the right safety and efficiency without a good quality of maintenance. More importantly, the maintenance can have an impact on the safety, human health and environment. In the old times the maintenance was the cost center of the companies. This old view means that you must buy good machine parts and hire the best maintenance technicians and engineers to repair the machines in order to run the whole production system perfectly. Too often, the top management ignores the fact that the added value maintenance can bring to an organization values such as [30] [31]:

- A reduction in reactive maintenance costs
- Reducing costs to restart production after a breakdown

- Limiting production scrap and quality complaints on long term
- Costs of downtime such as missed orders and lost revenue
- Increased customer satisfaction
- Improved quality of products
- Reduced environmental impact

The maintenance methods can add an economic value to the business and give a better a quality product on a long term. To view maintenance as a value driver method, the top management must move from cost based thinking to value based thinking. It is a very important phase to move to lean philosophy. [30] [31]

The founders of the value driver maintenance strategy are Mark Haarman and Guy Delahay. They wanted to optimize the value derived from maintenance at any particular point in time. The decision to perform maintenance at any time is based on cost/benefit analysis. It requires a delicate balancing between the value that improved reliability can bring and the cost of maintenance. [30] [31]

The following formula can be used in practice [30] [31]:

$$PVPM = \sum \frac{(FSHE,t) \times [(CFAU,t) + (CFCC,t) + (CFRA,t) + (CFSHE,t)]}{(1+r)^t} \quad (1)$$

PVPM = present value potential of maintenance

FSHE,t = SHE factoring year t (% compliance with SHE regulations)

CFAU,t = future free cash flow in year t from asset utilization

CFCC,t = future free cash flow in year t from the cost control

CFRA,t = future free cash flow in year t from resource allocation

CFSHE,t = future free cash flow in year t from SHE

r = discount rate

## 2.10 Computerized Maintenance Management System – CMMS

The computerized maintenance is based on different types of IT equipment. This method uses different kind of maintenance software. This software helps the maintenance teams keep a record about their activity, schedule the maintenance tasks and save the maintenance history. In the

practice one can distinguish two types of CMMS software. The first one is when the software runs on the client's computer or servers, the second is when it runs on the web. [32]

When a company is responsible for running its own CMMS system, it is called an on-premises CMMS system. The on-premises system has some advantages: the users have a high level of data privacy on a closed server, but the IT maintenance works is performed by the company IT experts. The main drawback is the expensive implementation costs of the CMMS system. The IT departments need to work on a high level. They have to be on duty (7/24) at the company, they have to learn and always have an up-to date knowledge in the fields of modern software and hardware. In addition, they have to always keep up to date the software versions. [32]

Nowadays the cloud platforms and services are very popular, it is enough to think about Microsoft One Drive, Google Cloud, Dropbox, etc. The CMMS software also can run on-line, it is the cloud-based CMMS. The cloud-based CMMS is operated by a subcontractor. The subcontractor has to take care of all the IT processes, like security, data saving, data policy, safety backups etc. Another strength of a cloud-based CMMS is that the software updates automatically, so you are always using the latest version. [32]

Advantages of CMMS [32]:

- Less failures, easy to schedule the preventive maintenance
- Better accountability: Quickly see if a technician did the work on time and get alerted when a task is complete (Industry 4.0)
- Less overtime: Better scheduling means that your team is not sitting idle or working overtime, which means that work can be distributed evenly, the companies can save cost on the human resources side
- Information capture and share with the organization, benchmark between the companies within the concern. Technicians and engineers can record problems and solutions, so this information is captured for others to use or it can be a feedback to the machine designers to develop better machines
- Savings on purchases side
- Data analysis, the data help management to make a better energy usage and develop better maintenance processes

The CMMS systems and software are very important to all types of maintenance fields. These kinds of solutions can help to manage plants and offices maintenance. In practice, we know four main groups where we can use CMMS technology. [32]

- Production maintenance: the CMMS works in the production area: in the production machines and in other support machines like forklifts or assembly lines. The operation of these machines are very important - if any failures happens the future of the company may be at stake (but this is the worst case). [32]
- Facility maintenance: this system controls the HVAC system, water supply and other energy systems; we can find these kinds of software in office buildings and in production areas too (for example: electrical industry where the production has to work at a defined temperature) [32]
- Fleet maintenance: nowadays the fleet maintenance is very popular, these companies use several vehicles on the roads. Their CMMS can contain GPS following function and help to analysis the fuel economy as well. [32]
- Linear asset maintenance: this is a special side of the CMMS technology - under this definition we can find the maintenance of roads, water pipes or cables. [32]

The companies which use CMMS technology show a demand for new possibilities of CMMS. The management level of the companies would like to see the result on any other device not only just the company computers. In addition, they would like to receive fast reports about the maintenance status. [32]

## 2.11 New era of CMMS technology

### 2.11.1 Mobile CMMS applications

Maintenance workers spend most of their time outside the office fixing machines and taking care of buildings. The exact documentation is very important for the technicians. This documentation requirement leads to the development of CMMS software for smartphones and tablets. These software are very popular in top management circles, who would like to know everything about the work of the technicians and engineers. With these applications the technicians can make records about their work, make notes or they can reach the drawings and documentations of the machines. [32]

### 2.11.2 Easy-to-use CMMS software

Many established CMMS companies make products that are very difficult to use. We know many complicated CMMS devices. The interface is the same since the 1990's. Most of the CMMS companies try to simplify the processes and try to develop different types of software which are easy to use in the daily maintenance routine. [32]

### 2.11.3 Fast CMMS data entry

Some CMMS systems are not so useful, because it is very complicated to write data into the system. The companies try to avoid these kinds of problems. The new CMMS developing strategy works on efficient ways and solutions to readily save data into the system. [32]

### 2.11.4 Cloud-based CMMS

Nowadays the software with individual demands are very popular solution. The CMMS firms focus on private CMMS technology which are running online. The CMMS company provides the support processes like IT security and backups. [32]

DUPress e-könyv

### 3. Maintenance triggers

When the maintenance is scheduled, and the time is here, the technicians and engineers have to solve the maintenance tasks at an operation level. The maintenance triggers are the tools which alert the maintenance team to start the maintenance process. The organization with maintenance triggers can make or plan the maintenance and start to use a CMMS system. [33]

In practice we can use five main maintenance triggers, which are the following: breakdown, time-based, event-based, usage-based, and condition-based. [33]

#### 3.1 Breakdown trigger

The breakdown triggers are activated when the machine or machine parts break down and the production operators, team leaders, technician or the machine operators cannot use them with a right safety or with right efficiency. These maintenance triggers mean that, the maintenance is necessary, and the maintenance team has to start it as soon as possible. The breakdown trigger is used when the maintenance team have not got a plan or a strategy about the local maintenance. If the company uses a run-to-failure maintenance, the breakdown trigger is the only used trigger. It means the following: the maintenance is unscheduled. If the machines has a preventive maintenance strategy, the breakdown trigger initiates maintenance, so it is unplanned or unscheduled. We can find this trigger in the following strategies: corrective, reactive and run-to-failure. [33]

#### 3.2 Time trigger

The Time trigger is very easy to use as a trigger to determin the maintenance frequency. The time trigger activates when the calendar reaches a defined day or time. Because the calendar is so easily predicted, time is the least complex trigger to schedule planned maintenance. The engineers can use time as a trigger in many ways. It can be used like regular intervals, for instance in every six weeks or one can define a bigger gap, based on seasons, for example: change the winter tires before the winter. We can find this trigger in the following strategies: preventive, condition-based and predictive. [33]

#### 3.3 Usage trigger

The usage trigger is popular by vehicle manufacturers especially for cars. This trigger helps to schedule the maintenance of the cars. For example, the car manufacturers define a kilometer range to the vehicles, also to the petrol and the Diesel engines. This type of maintenance is triggered

through recorded meter data. Other examples include usage based on hours of use and number of production cycles. We can find this trigger in the following strategies: preventive, condition-based and predictive. [33]

### 3.4 Event trigger

It is a very easy trigger. The maintenance must be activated if any external event happens. A good example for this trigger is a building with a flooding. If the building has a flooding in the basement the maintenance tasks need to be triggered. These tasks could include electrical checks, HVAC check or structure check. We can find this trigger in the following strategies: preventive, condition-based and predictive. [33]

### 3.5 Condition trigger

*“The definition of condition-based trigger is the following: A condition-based trigger for maintenance occurs after the condition of the equipment has been assessed and consequently determined to be unsatisfactory for continued use without maintenance being planned.”* [33] In practice we can use several techniques to check the condition of machines and machine parts. We find a lot of inexpensive techniques like visual inspections or we can use expensive tools, such as vibration monitoring or thermographic cameras. [33]

The condition based trigger is a very complex trigger. Sometimes it is not easy to understand because the data are not straightforward to obtain and interpret. The maintenance team need a special condition monitoring equipment and special training plus experience to use these kinds of tools. With these skills the technicians can analyze the data and information with high reliability and they can indicate that the maintenance is required or not. We can find this trigger in the following strategies: condition-based and predictive. [33]

## 4. Industry 4.0 – The new industrial revolution?

At the beginning of the 21<sup>st</sup> century a lot of new IT solutions came into the daily life of manufacturing and maintenance systems. The companies started to use several automation and internet based technologies. In the early years of the 2000s' the governments, the press and the representatives of the industry started to speak about the new industrial revolution. This is what we call Industry 4.0 or Industrie 4.0. These words cover the nowadays popular automation, data exchange, cyber-physical, Internet of Things (IoT), cloud services and technologies. [34-55]

The Industry 4.0 defined the concept of smart factory. (Good to know, the European Union started to make Smart cities to find the way how can make better cities for the citizens. For example: Smart City Debrecen, Hungary. These programs try to make a connection between the industrial solutions and the new technical solutions in the cities.). The factories of the new era show a modular structure. These structures contain different cyber physical systems and other measuring systems, which can measure the processes and make a virtual space about the actual physical world and make decentralized decisions possible. These systems can make up a real-time communication system and they can communicate with each other and with humans also. The Internet of Things and other solutions make cross organizational channels and can be used by the whole organization also for internal and external services. [34-55]

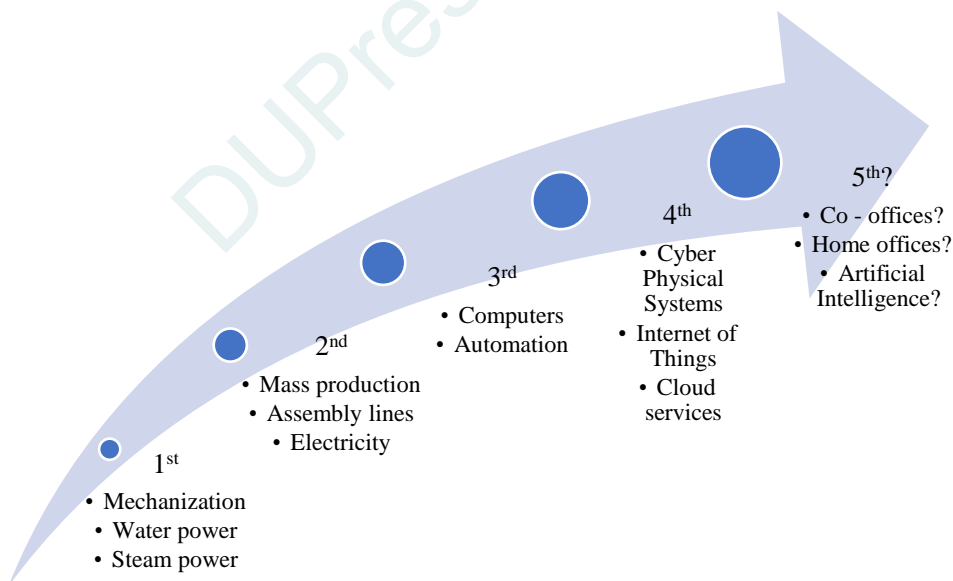


Figure 5.: The evolution of the industry [54]

The name of the new industrial revolution came from the new high tech industrial strategy of the German government. This is the reason why we can find the term "Industrie 4.0" with the German spelling. [34-55]

The Industry 4.0 was reviewed in 2011 at the Hannover Fair in Germany. This is one of the biggest industrial fairs in Europe and also all around the world. In the previous year a Work Group was formed from the most important industrial and government members. This group worked on the rules and processes of Industry 4.0. The team presented their set, implementation and recommendations to the German government about the Industry 4.0 in October 2012. The Industry 4.0 Work Group contained the following workgroups [34-55]:

- Co-Chair Henning Kagermann and Siegfried Dais
- The Smart Factory: Manfred Wittenstein
- The Real Environment: Siegfried Russwurm
- The Economic Environment: Stephan Fische
- Human Beings and Work: Wolfgang Wahlster
- The Technology Factor: Heinz Derenbach

The final report from the Work Group was presented on 8th of April in 2013, also in the Hannover Fair. The presentation defined 4 main design principles of Industry 4.0. These principles can give a support for the companies to implement the Industry 4.0 successfully in practice. These principles are the following [34-55]:

- Interoperability
- Information transparency
- Technical assistance
- Decentralized decisions

The current definition has been criticised from many points of view. The technology has a continuous innovation and the concept of the revolution in the technology innovation is based on a lack of deep knowledge of the details. [34-55]

The main characteristic of Industry 4.0 came from the German government. The new industrial strategy contains the following: *"the strong customization of products under the conditions of highly flexibilised (mass-) production."* [54] The required automation technology is very important, it improved by the introduction of methods of self-optimization, self-configuration, self-diagnosis, cognition and intelligent support of workers in their complex work. The largest project in Industry

4.0 as of July 2013 is the BMBF leading-edge cluster "*Intelligent Technical Systems Ost Westfalen Lippe (OWL)*". [54] Another major project is the BMBF<sup>5</sup> project RES-COM<sup>6</sup> as well as the Cluster of Excellence "*Integrative Production Technology for High-Wage Countries*". [54] In 2015, the European Commission started the international Horizon 2020 project CREMA (Providing Cloud-based Rapid Elastic Manufacturing based on the XaaS and Cloud model) which is a pioneer of Industry 4.0. Governments and Majors would like to adjust Industry 4.0 to Sustainable Energy and Climate Action Plan too. [34-55]

In 2013 the history of Industry 4.0 reached a milestone. The firm of McKinsey had an interview between the executives at Robert Bosch - Siegfried Dais (Partner of the Robert Bosch Industrietreuhand KG) and Heinz Derenbach (CEO of Bosch Software Innovations GmbH) - and McKinsey experts. The main topic of this interview was the Internet of Things (IoT) in manufacturing and its effect on the industrial processes. These conditions are called Industry 4.0 in Germany. The basic principle of Industry 4.0 is depending on connecting machines, production lines, factories and systems, businesses are creating intelligent networks along the full supply chain value chain and network that can control each other autonomously. [34-55]

The new era of the machines can predict failures and trigger maintenance processes autonomously or can make self-check and organized logistic processes with the tools of artificial intelligence. These new possibilities can make changes in the production on short and long terms as well. [34-55]

According to Dais, "*it is highly likely that the world of production will become more and more networked until everything is interlinked with everything else*". [54] This sentence is looking for the not far future. The Industry 4.0 makes a good opportunity to the production and supplier networks will grow enormously. Just think about smart phones and the other connected services like cloud systems, or alarm/safety systems. Nowadays in most of the factories the networks and processes have just been limited to the local plant or shopfloor. Industry 4.0 breaks the limits of the network technology. In the future we will not see the limit between the plants and services. The new networks system will have the main task: they have to interconnect multiple factories not only in one city, but in the entire region! [34-55]

The previous paragraphs show some differences between a traditional factory and an Industrial 4.0 factory. In the current life of factories, providing high-end quality service and/or product with the

<sup>5</sup> Bundesministerium für Bildung und Forschung

<sup>6</sup> Resource Conservation by Context – Activated M2M Communication

least cost. They use new production control philosophies to reach the dream goal in the practice. This philosophy can be the Lean philosophy which is the most popular technique today to improve production processes and other services. Various data are available to provide information about different aspects of the factory. In this stage, the utilization of data is for understanding current operating conditions and detecting failures and breakdowns in the system. For example, the Overall Equipment Effectiveness (OEE) can give information for the factory management in order to highlight the root causes of problems and possible faults in the company. Also, we can speak about the lot of key performance indicators which help to give information about the efficiency of the production and support processes. [34-55]

The factories with Industry 4.0 strategy show a difference. In these factories all of the machines can make condition monitoring, fault diagnostic and self-check. The machines can make self-awareness and self-productiveness. With these properties the factory management can make a new operation strategy and get a deeper information and experience about the machines and processes. [34-55]

The parameter deviations can use a new range and grant a new operation limit to the production, if the machines have a good communication system and they can communicate with each other. The new operation strategy can provide a better efficiency, cost saving and better-quality product. [34-55]

The main challenges in implementation of Industry 4.0 [34-55]:

- IT security issues, open manufacturing.
- Reliability and stability needed for critical machine-to-machine communication (M2M), including very short and stable latency times
- The maintain the integrity of production and production support processes
- Avoid IT failures and mistakes, these problems can make expensive production breakdowns
- Security of industrial know-how
- The importance of missing skills during the implementation of Industry 4.0
- Less employee at IT departments
- Lot of unemployed, it depends on the automatic processes, Artificial Intelligence and other automatic process evolution, it is important for the lower educated parts of society

The IT solutions (IoT, big data analysis etc.) can give a big support to the organization to investigate, solve or avoid problems. Very important to eliminate the problems, before it has any

effect on the product. The Industry 4.0 Cyber Physical Systems consists of 6Cs for. The 6Cs are an important tool for Big Data analytics. The 6C system comprises [34-55]:

- Connection with sensor and network systems
- Cloud services
- Cyber systems
- Content/context (meaning and correlation)
- Community sharing & collaboration
- Customization

To get useful data one needs to use advanced analytical tools and algorithms. The modern programming algorithm can deliver the right information and data to the factory management. These data will contain meaningful information. These kinds of software and algorithms have to give an answer about the hidden failures, problems and contexts. If the hidden problems are cannot be seen the whole factory efficiency and safety can go down dramatically. [34-55]

Another parts of industrial environment which are claim Industry 4.0 affect [34-55]:

- Services and business models
- Reliability and continuous productivity
- IT security
- Machine safety
- Product lifecycles
- Industry value chain
- Workers' education and skills
- Socio-economic factors

## 5. Key Performance Indicators

In the daily routine it is very important to monitor our activities or our health. Just think about the blood pressure or your weight. These numbers can give information about our health or status. If we have any problem with our blood pressure we have to make a discussion with the doctors, get some pills and we have to reach the right blood pressure. This new pressure is our target. In industrial field we can find similar numbers. In the practice we call these numbers performance indicators or key performance indicators (KPI). These indicators are a type of a performance measurement. The KPI numbers can evaluate the success of the teams, production areas and/or the whole factory. We can define KPI numbers for programs and projects which can show the efficiency of the projects. They are sometimes used simply to describe the success of processes or production, for example: zero defects. But in most cases success is defined on a long term with strategic goals. Choosing the right KPI(s) is very important. In the first step we have to understand what is the target of the organization. The management always measure a lot of independent target in the practice. All members of the organization must follow these targets and the KPI numbers. In the practice, we can find dozens of techniques which can help us understand and present the state of the business, key figures and activities. These estimates often show the potential improvements and the KPIs are 'walking hand in hand' with these estimates. The easiest solution to choose the right KPIs is to use a management framework structure like the balanced scorecard. [56-58]

The performance indicators define the values what the organization has to measure. This is what we can simply call indicators. We can speak about various categories in the field of key performance indicators. These can be the following [56-58]:

- Quantitative indicators, presented as a number
- Qualitative indicators, cannot presented as a number
- Main key performance indicators that can describe the outcome of a process
- Key Performance Indicators which can show the success and the failures of a process and developments
- Input indicators, important to measure the quantity of the resources during the process
- Process indicators that represent the efficiency and/or the productivity of the process
- Output indicators that show the outcome of the process and developments
- New indicators which can connect to the company processes

The most important indicators are used for strategic development for both short and long terms. These numbers can give the most valuable information on the business. Sometimes we can call them 'key success indicators'. [56-58]

Good to know: in practice the performance indicators show a difference from the business drivers and goals. For example, football teams can consider the number of the goals per season which can help to understand their position in the championship. But we can see another approach in business field: companies can consider the percentage of income from returning customers as a potential KPI. [56-58]

In the practice, it is easy to check the following steps to identify the useful KPI numbers to our organization [56-58]:

- Pre-defined business process (BP)
- You have to know and understand the requirements for the BPs
- You have to use quantitative/qualitative measurement of the results
- Always compare the results with the defined goals
- Investigating variances and resources to achieve short-term goals

As we can see the KPIs are the most important tools to check and measure the efficiency of an organization, business units, teams or employees. Accordingly, KPIs are the most commonly defined to be understandable, measurable and meaningful for everybody in the organization. [56-58]

The KPIs are perfect tools to follow the performance of the production and nonproduction processes. This fact has an important meaning. The measure has a purpose for the business, the process is measurable, and the defined norms have to be achievable for the whole organization. The KPIs must be time phased. [56-58]

However, only the KPI numbers are not enough as you can read in the first paragraph of this chapter. We have to define target values. These target values can show if the measurement can be assessed as meeting expectations or not. [56-58]

## 5.1 Manufacturing or Production areas

In the manufacturing systems or in factories we can, and we have to use a lot of performance indicators. The most important one is the overall equipment effectiveness (OEE). This number

gives percentages for the factory management to show the equipment effectiveness. It is built up from three different values. Later the reader will get a deeper explanation about it. [59-61]

Here are some other examples for manufacturing key performance indicators [59-61]:

- Availability = run time / planned production time, this number is a percentage of the actual amount of production time the machine (or production line) is running to the production time the machine is available
- Performance = (ideal cycle time x total count) / run time, this number is the percentage of total parts produced on the machine (or production line) to the production rate of machine (or production line)
- Quality = good count / total count, by definition, this is the percentage of good parts out of the total parts produced on the machine (or production line)
- Cycle time ratio = standard cycle time / real cycle time

## 5.2 Supply chain management or Logistic areas

Companies can use KPIs to monitor the targets of a lot of processes and services, like manufacturing improvement (lean), environmental improvements, etc. The companies can – independently of their size – manage better supplier performance with the help of the KPIs robust capabilities, which include [56-61]:

- Automated entry and approval functions
- On-demand, real-time scorecard measures
- Rework on procured inventory
- Single data repository to eliminate inefficiencies and maintain consistency
- Advanced workflow approval process to ensure consistent procedures
- Flexible data-input modes and real-time graphical performance displays
- Customized cost savings documentation
- Simplified setup procedures to eliminate dependence upon IT resources

The main supply chain KPIs detail the following processes [56-61]:

- Sales forecasts
- Inventory
- Purchasing and suppliers
- Warehousing (Raw material, Finish goods)
- Transportation (Logistic)

In practice the companies use a lot of KPI numbers, but in some cases, it is expensive to measure and difficult to understand for the machine operators or for the whole organization. Some indicators are impossible to measure, like staff morale. These numbers cannot give a good picture about the current situation or status - these are just a rough guide. [56-61]

The Key Performance Indicators can show the result and the value of the work of the employees. The measurement helps to find and define the problems in the processes. [56-61]

### 5.3 Basic maintenance metrics

As the previous chapter shows, we have to use key performance indicators to measure our activity. The question is: Which KPI numbers are important in the field of maintenance engineering? The way to success is to establish the baseline in order to try to improve something, such as a process, a product or a machine. One good example came from the founder of the Microsoft Inc., Bill Gates. He spoke about the steam engine, which is one of the most important inventions in the industrial age. It was designed and developed by a lot of changes and feedbacks from the customers. "Without measurement," writes William Rosen, invention is "doomed to be rare and erratic." But the criteria of the steam engines were very simple. The most important properties were the weight, working with less fuel and cheaper to construct. [59-62]

The same is true for maintenance metrics. Thousands of books and scientific articles are full with different performance indicators, which we can use in daily maintenance engineering work. [62]

For example: the downtime minimizing looks like a good idea, if it has no negative effect on the product quality or on the employees. It cannot countervene the long-term production strategy or any maintenance strategy. During the optimization a lot of confounding factors to be considered. The situation can be serious when the maintenance metrics become an obstacle. [62]

The balanced scorecard had its debut at the beginning of the 1990's. This system encouraged the managers, leaders and CEOs to follow their departments and organizations with variety of metrics. The basic idea was to avoid the optimizing area at the expense of another. The engineers increased the machine availability with a high spare parts stock, the result: the OEE improves, but the inventory costs increased. Important to know: the measuring performance based solely on financial and purchasing indicators alone give a false picture about the actual situation. [62]

The balanced scorecards made a clear and effective system to analyze and check the companies on a high level and made a way of the developments in the future on a short and long term too. [62]

Table 1.: KPI number examples to different areas [62]

Critical Success Factor	Key Result Area	Key Performance Indicator
Financial Performance	Costs Revenue	Maintenance cost/unit ROI (return on investment)
Customer Satisfaction	Quality Service	Number of complaints Value for money Referral
Process Performance	Equipment performance	OEE
Employee/Environmental Safety	Health Safety Legal Requirements Environment	Number of accidents Number of HSE complaints Employee complaints

Table 1. contains a useful approach and examples to bring the organization closer to the integrated maintenance with high level goals. [62]

#### 5.4 What is Mean Time to Repair?

The Mean Time to Repair (MTTR) is an average calculated time what is required to avoid maintenance problems and repair failed equipment and tools and return to the normal operation condition. It is a basic technical measure of the maintainability of machines and tools. Another important definition is the maintenance time. This time can be defined as the time between the start of the failure and the moment when the system returns to the normal production. Or in an easy wording: it is the time how long the equipment is out of production. The maintenance time include a lot of sub time and process steps: notification time, diagnostic time, fix time, wait time (cool down), reassembly, alignment, calibration, test time, back to production, etc. In the most cases it does not take into account the lead time for parts. The Mean Time to Repair can give a mirror about the efficiency of the maintenance team. It reflects how well the maintenance team can respond to the problem and fix it. [63]

The Mean Time to Repair is easy to calculate with a mathematical formula. It is the total maintenance time divided by the total number of maintenance tasks, which are over the specific period. The formula is the following [63]:

$$MTTR = \frac{\text{total maintenance time}}{\text{number of repairs}} \quad (2)$$

These failures are always changing during the lifetime of the machines and tools. Some failures need no complicated diagnosis or investigation – it is just enough to change a part, but in some tasks, one needs to use some difficult machine repairing techniques and diagnostic tools. The frequency vs. repair time plot follows the log-normal distribution. In the practice the following

simple rule holds: large number of repairs are quick and small number of repairs need more time. [63]

The Mean Time to Repair of the bottle neck machines could have a catastrophic effect on the whole factory. Very long maintenance time causes big losses for the company. During the maintenance the company cannot make products and it could miss orders and other business opportunities. To avoid these problems companies, have own maintenance team and hold spare parts or run more production lines in parallel with each other to ensure a bigger flexibility and safety of the system. [63]

Prediction on the number of hours when any machine parts or system are not available while undergoing maintenance is very important. MTTR contains a lot of information on what can help the engineers to make decisions in the maintenance process such as repair or replacing machine part or making a new maintenance plan of the machine. For example: an old machine needs more time than a new one. The MTTR shows a growing trend in the repairing time. This time gap between the starter and the new time can be a good tool for the maintenance engineers and the company management to develop their maintenance strategy and production plan. [63]

MTTR can be useful to calculate performance or to calculate the life cycle of the next cost system. Nowadays, the modular design and platforms are very important in the circle of designers. Thanks to this technique the assembly process is now easier than ever. For example: the vehicle factories use modular chassis platform. The Volvo use a Compact Modular Architecture (CMA), which is used for smaller Volvo cars (2017). The company management always have to make a good decision about the purchasing questions. The company can make a lot of stress for the maintenance department, which buy a machine with a high MTTR timer and with a catastrophic design where the engineers and technicians cannot make maintenance or difficult to make it. This additional time and costs should be in focus into the life of the machine and production and put them into focus at the purchasing questions. Manufacturers also use MTTR to justify redesigning or improving systems. [63]

In the practice the management have to know the following principles [63]:

- One technician can make all of his/her tasks sequentially
- The maintenance team have members with a good knowledge about maintenance theoretical background and practice

## 5.5 Mean Time Between Failures (MTBF)

The other important performance indicator is the Mean Time Between Failures (MTBF). The MTBF shows the failure rate of the machines and machine parts need to be managed by the maintenance group. It is nothing other than an average time between the breakdowns or from another point of view, it is an average time when the machine functions between breakdowns. This time is a critical indicator in complex systems with a high risk and safety. These kinds of systems can be generators, elevators or airplanes. This is the reason why MTBF becomes a fundamental component in the design of machines with high risk and safety. Important to know: the MTBF does not care about the scheduled maintenance or any other time like logistic process or lubrications etc. The MTTR affects availability, mean time between fail affects availability and reliability. [64]

The unit of mean time between fail is usually hours. The MTBF includes only the operational time between failures, it does not include any other repair time. [64]

In the practice we can find a lot of items which can modify the result of Mean Time Between Failures, the most critical factor is the human factor. The machine operators and the maintenance team members have not the same skills and experience. If the management forget to avoid these problems, they will calculate a wrong result. [64]

$$MTBF = \frac{\sum(\text{Start of Downtime} - \text{Start of Uptime})}{\text{Number of Failures}} \quad (3)$$

The MTBF can show how likely a single unit is to fail within a certain period of time. So, MTBF is a great tool or technique to measure the reliability of a system or a machine. This average time means that, the asset works normally before its breakdown. It can be used to predict future performance and efficiency. For example: automobile break down assistance. [64]

Manufacturers can give the predicted MTBF results for systems, machines or machine parts. These results are based on a lot of experiments and prototypes. The MTBF calculation results can be depend on the machine design. To get the correct data, one has to use the local information for the calculation. If it is possible, the data have to come from a computer based maintenance system. If it is not possible, you have to find an offline solution. [64]

MTBF can also be useful in determining the frequency of inspections or preventive replacements. If your system is failing for the same reasons, you could use the MTBF data to introduce some preventive actions such as greasing, inspections, calibrations, preventive repairs etc. [64]

MTBF is very useful to give an important performance indicator in the practice. It can influence the design of a new maintenance system. It helps to improve the production processes and quality products with a lower stress level. The data log of MTBF is a key success in a modern factory life to design the company strategy on a long term. [64]

## 5.6 Overall Equipment Effectiveness (OEE)

Nowadays the most important key performance indicator is the Overall equipment effectiveness or OEE. It can show the availability of the machines or production lines. It describes three main factors also, namely the efficiency, performance and quality. It helps to identify areas where the production has to improve and develop. We can calculate it with the contributing previously mentioned three factors. [59-61] [65]

$$\text{Overall Equipment Effectiveness} = \text{availability} \times \text{performance} \times \text{quality} \quad (4)$$

- Availability – System(s), machine(s) or production line(s) is/are functioning when it is needed
- Performance – System throughput divided by its maximum throughput
- Quality – The number of good units divided by total units started

One of the big advantages of OEE is that it excludes the planned shutdowns, like holidays or scheduled maintenance etc. In summary, the planned production time what is needed to calculate overall equipment effectiveness. We can read about a lot of information from these numbers, the dream factory looks like the following: it is one that produces the best product, as quickly as possible, with no unscheduled down time. This is the 100% OEE, but it is impossible to reach in the practice! For certain manufacturing plants, world class OEE is generally considered being 85% or better. However, the average OEE score is ~60%. We can find big differences between the industrial fields. The OEE is one of the best indicators in the daily production routine. OEE also provides a way of measuring the success of manufacturing, productivity or lean activities like TPM. Important to know: the OEE formula is used in a general form in this book. We can find a lot of versions of OEE in the practice. It means that the companies use a little modification in the formula, the three main factors will not change but the deeper meaning of each factor can be modified. It is very important to see the factors clear. If the formula and the factors are clear, we can avoid a lot of misunderstanding or wrong performance indicators in the future. As the previous chapter contains, a wrong key performance indicator can show a bad way for a company with unpredictable consequences. [59-61] [65]

Table 2.: 'Ideal' and 'Normal' OEE results [65]

	<b>Ideal</b>	<b>Normal</b>
<b>Availability</b>	90%	79%
<b>Performance</b>	95%	80%
<b>Quality</b>	99.9%	95%
<b>OEE</b>	85%	60%

After the identification of the three factors we can calculate the OEE. If we see the three factors it is very easy to find the potential place for the improvements. The factors can come online or offline like papers or Microsoft Excel data base, but nowadays the standards contain details about to use company detailed systems. Big companies use these kinds of software, for example: SAP or Oracle etc. In reality, OEE measures the losses that affect your equipment. The 6 big losses are [59-61] [65]:

1. Equipment failures
2. Setup and adjustment time due to product changeover
3. Idling or minor stoppages (for example: misfeeds, sensor errors etc.)
4. Reduced speed due to rough running or equipment wear
5. Defects in operation or process
6. Startup (for example: after changeover) or reduced yield

It is very important to find and define the performance indicators. By doing so the company can get into a competitive advantage position in the market. The efficiency is the area that every production company can improve and the OEE is the best tool to measure it. The management have to know the overall equipment effectiveness. If they have not got any information about it, they have not any real information about effectiveness of the company. Table 3. contains the three factors and some details where and what you can improve. [59-61] [65]

Table 3.: Improving areas [65]

Dependency	What kills it?	How can I improve it?
<b>Availability</b>	Breakdowns Machine idle time Adjustment time Stoppages	Improve PM scheduling Reduce reactive maintenance Retrain personnel Effective parts strategy Knowledge
<b>Performance</b>	Poorly operating equipment Inefficient work processes Material variations Lack of lubrication Older systems	Equipment overhaul Regular equipment PMs Replacements
<b>Quality</b>	Poorly maintained equipment Systems misalignment Inconsistent raw materials Guesswork	Improve the quality of raw materials

The factors can be calculated with the OEE equation or you can use software. The software can give a stability for the company. *“According to David Berger of Plant Services, a CMMS could deliver a 10% increase in availability, a 5% increase in throughput and a 5% increase in quality of output. With a fully functioning CMMS, coupled with a preventive maintenance philosophy, these gains result in a significant improvement in OEE and hence the company financials.”* [59-61] [65]

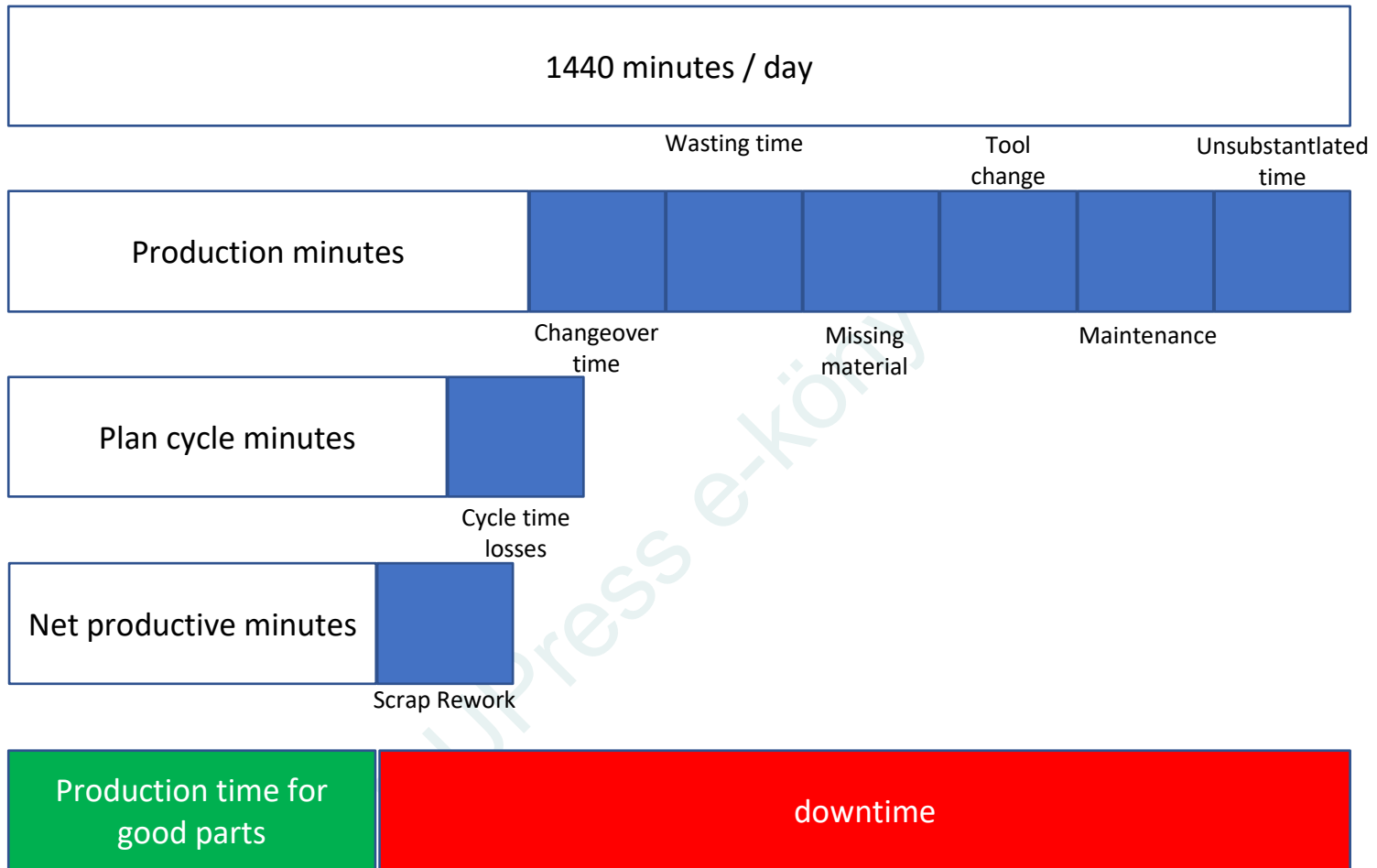


Figure 6.: TPM „time line” [61]

The overall Equipment Effectiveness is influenced by various losses and is made up of availability (A), output (O) and quality factor (Q). We can calculate them with the following formulas [59-61]:

$$AF = \frac{\text{total availability} - \text{unplanned downtime}}{\text{total availability}} \quad (5)$$

$$PF = \frac{\text{production minutes} - \text{cycletime}}{\text{production minutes}} \quad (6)$$

$$QF = \frac{\text{plan cycle minutes} - \text{scrap minutes} / \text{rework minutes}}{\text{plan cycle minutes}} \quad (7)$$

Let's see two examples:

1. Example [59-61]:

$$AF = \frac{\text{production minutes} \times 100\%}{\text{planned minutes}} = \frac{510 \times 100\%}{1440} = 35.4\% \quad (8)$$

$$PF = \frac{\text{planned piece minutes} \times 100\%}{\text{production minutes}} = \frac{435 \times 100\%}{510} = 85.3\% \quad (9)$$

$$QF = \frac{\text{net production minutes} \times 100\%}{\text{planned piece minutes}} = \frac{426 \times 100\%}{435} = 97.9\% \quad (10)$$

$$OEE = AF \times PF \times QF \quad (11)$$

$$OEE = 0.354 \times 0.853 \times 0.979 \times 100\% = 29.6\% \quad (12)$$

2. Example [59-61]:

Basic data:

Shift length: 8 hours = 480 min.

Short Breaks:  $2 \times 15 \text{ min.} = 30 \text{ min.}$

Meal Break: 30 min.

Down time: 47 min.

Ideal Run Rate: 60 pieces / minute

Total Pieces: 18371 pieces

Rejected Pieces: 523 pieces

$$\text{Planned Production Time} = \text{Shift Length} - \text{Breaks} \quad (13)$$

$$\text{Planned Production Time} = 480 - 60 = 420 \text{ minutes} \quad (14)$$

$$\text{Operating Time} = \text{Planned Production Time} - \text{Down Time} \quad (15)$$

$$\text{Operating Time} = 420 - 47 = 373 \text{ minutes} \quad (16)$$

$$\text{Good Pieces} = \text{Total Pieces} - \text{Reject Pieces} \quad (17)$$

$$\text{Good Pieces} = 18371 - 223 = 17848 \text{ pieces} \quad (18)$$

$$\text{Availability} = \frac{\text{Operating Time}}{\text{Planned Production Time}} \quad (19)$$

$$\text{Availability} = \frac{373}{420} = 0.8881 = 88.81 \% \quad (20)$$

$$\text{Performance} = \left( \frac{\text{Good Pieces}}{\text{Total Pieces}} \right) \div \text{Ideal Runrate} \quad (21)$$

$$\text{Performance} = \left( \frac{17848 \text{ pieces}}{373 \text{ minutes}} \right) \div 60 \frac{\text{pieces}}{\text{minute}} = 0.7974 = 79.74\% \quad (22)$$

$$\text{Quality} = \frac{\text{Good Pieces}}{\text{Total Pieces}} \quad (23)$$

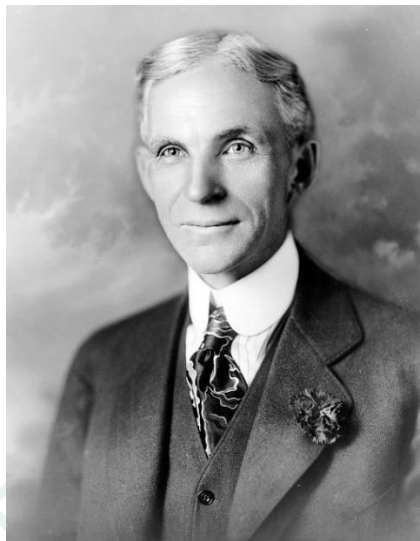
$$\text{Quality} = \frac{17848}{18371} = 0.9715 = 97.15\% \quad (24)$$

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (25)$$

$$\text{OEE} = 0.8881 \times 0.7974 \times 0.9715 = 0.6879 = 68.79\% \quad (26)$$

## 6. Short history of Lean

The process optimization and the demand for it can be found already in the middle ages. But the first person in the modern age, in the 20th century who started to understand the importance of process development was Henry Ford in the United States (Figure 7.). He had a factory in the State of Michigan in Highland Park. In 1913 he made a revolutionary step towards industrial processes known and used nowadays. He made the connection between the consistently interchangeable parts with standard work and moving parts to create what he called flow production. It was the new era of the production, he designed the first moving assembly line in the world, but the breakthroughs went further from the point of view of engineering. [66-71]



*Figure 7.: Henry Ford [67]*

Ford checked the assembly steps, he lined them up and made a process sequence. Where he had a chance, he used special machines and go/no go gauges. Thanks to these tools and techniques the operators just had to work few minutes with the machine parts and they could put them into the vehicles. The go/no go gauges are very popular today and we can find them in quality field. These gauges help to deliver good parts to the next workstation, but good to know that the measuring results with go/no go gauges are inaccurate. These actions changed the basis of the American assembly system. In the old system the machines consisted of a general purpose and were grouped by processes. [66-71]

The basic concept from Ford was good. The main problem was the production mix. What does it mean? The answer is simple: The Ford Model T was just made in one color. So the production was

limited to only one specification. All Model T chassis were basically the same until the end of the production in 1926. The customers had a choice, they could buy five different body styles and at the end of the production line the drop on features added from outside suppliers. It looks like the old Ford company never had a changeover in their production. [66-71]

The world changes. The customers wanted a variety of cars, the Model T cycles were 19 years and it was too long. Ford lost his way and position in the industrial competition. Other car manufacturers gave the answer to this customer demand. The vehicle companies started to design new cars with a lot of extra accessories, but they forgot to develop and improve the industrial, logistic and assembly processes. The production time was long, very long. What do the customers want? Get their product as soon as possible! The factories used modernized machines, they were faster and started to use high stock levels. They just apparently solved the problems. *“Even worse, the time lags between process steps and the complex part routings required ever more sophisticated information management systems culminating in computerized Materials Requirements Planning (MRP) systems.”* [66-71]

The biggest breakthrough came from the other side of the world. It came from Japan after the second World War. Japan was in a chaotic phase. The industry of the country was in ruins. They had to find out something. The solution came from Taiichi Ohno (Figure 8.), at Toyota company. He felt that a lot of simple innovations can create a better production and material flow in their plant. He redesigned Ford's original ideas, and invented the Toyota Production System (TPS), what is the basis of today's production systems. [66-71]



Figure 8.: Taiichi Ohno [71]

This method modified the focus of the engineers. They started to analysis the processes and the flow throughout the whole supply chain. The Toyota made a new point of view. If they choose the

right size and capacity of the machine for the actual volume and introduce self-monitoring machines to ensure quality, put the machines into line, build up a process sequence, pioneer quick setups so each machine could make small volumes of many part numbers, and have each process step notify the previous step of its current needs for materials, then it would be possible to obtain low cost, high variety, high quality, and very rapid throughput times to respond to changing customer desires. The information management and key performance indicator system became much simpler and more accurate. [66-71]

The new process development tools and the Toyota Production System what we use nowadays are called the Lean production philosophy. The most important book in this topic is the following: '*The Machine That Changed the World*' (1990) by James P. Womack, Daniel Roos, and Daniel T. Jones. This book contains a deep theoretical background of lean and process improvement techniques used nowadays in a modern factory. In a subsequent volume, (1996), James P. Womack and Daniel T. Jones distilled these lean principles even further to five [66-71]:

- *"Specify the value desired by the customer*
- *Identify the value stream for each product providing that value and challenge all of the wasted steps (generally nine out of ten) currently necessary to provide it*
- *Make the product flow continuously through the remaining value-added steps*
- *Introduce pull between all steps where continuous flow is possible*
- *Manage toward perfection so that the number of steps and the amount of time and information needed to serve the customer continually falls"*

The Toyota Motor Company became the world biggest car manufacturer and leads the world in lean philosophy. The company is dominant on the markets, the sales are rising, the company is the most important pioneer of clean energy like hybrid technology or electric cars. The power of the Toyota company comes from the lean philosophy and the respect from the company management towards the employees and machine operators. [66-71]

Other companies would like to get a success like Toyota Company. We can find thousands of books, articles, papers, theses and websites about lean topic. Consultant companies grow from the ground and start to help companies to introduce lean philosophy into their activity, production or services. [66-71]

We can find lean principles all around the world, but not only at production areas. Nowadays governments, service centers and offices try to implement lean principles into their work. Just think

about healthcare: if the doctors and nurses can get more time in their work maybe they can save more lives or they can work with less stress in their daily routine. Sometimes it is difficult to understand why it is so easy to use lean principles in Japan and why so difficult in Europe or in the western part of the world. The answers are a bit complicated. Lots of problems come from political and historical background. Others come from the cultural customs of the country. However, one thing is sure: Toyota Motor Company has more than 60 years advantage. [66-71]

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## 7. Just in Time

Just in Time (JIT) is a very popular management philosophy which we can find in production field and many other areas like logistics or services. We can also find it in books, which are dealing with lean topics. The origins of this philosophy came from the production where the processes meet with the customer demand exactly, in the right time, in the right quality and in the right quantity. It is a such a basic concept: the customer does not want more or less of the ordered quantity, does not want it in a bad condition or quality and finally, he does not want it earlier or later than the originally agreed date. Does not matter if the customer is the final purchaser of the finished goods or he is another step in the production process. [71-73]

Elements of JIT include [71-73]:

- Continuous Improvement (CI) and CI tools
- Eliminate all of the basic or fundamental problems and wastes, avoid anything that does not add any value to the product
- Design system to identify and eliminate problems and failures
- Try to develop simple system, simpler systems may be easy to understand to machine operators
- Product oriented layout and plants, try to spent less time moving of materials and parts
- Quality control station, important to know: each worker is responsible for the quality of their own output
- Develop Poka Yoke tools and equipments
- Total Productive Maintenance (TPM), Preventive Maintenance (PM), always improve maintenance processes
- Good housekeeping - clean workplaces and shopfloor
- Set-up time reduction - increases flexibility and allows smaller batches. Ideal batch size is only one item (it is the basic of one-piece flow)
- Multi - process handling - it is a multi - skilled workforce/employees has greater productivity, flexibility and job satisfaction
- Production mix
- Jidoka (Autonomation) - providing machines with the autonomous capability to use judgement, so workers can do more useful things than standing watching them work
- Andon lights - to signal problems to initiate corrective action

The origins of the JIT are from Japan. This philosophy has been applied since the early 1970s in many Japanese manufacturing companies. Taiichi Ohno was the first who developed and perfected the manufacturing systems and processes as a means of meeting customer demands with minimum delays. This is the reason why Taiichi Ohno is the father of Just in Time philosophy. The Toyota Company was able to satisfy the customer demands and other industrial challenges through an approach in which they put the focus on the people and systems. Toyota was the first company who realized what are the criteria of the successful just in time system. If the entire organization is a participating member of the implementation of the just-in-time system and processes work on a maximum output and efficiency and the quality of the products is high, then the company can meet the customer demands. [71-73]

The just in time systems can work on a high level if the whole organization can feel the 'vibe' and importance of the system. The employees can make a better system and production with their experience and knowledge and thereby they can create a competitive advantage of the company.

These rules demand strict and strong cultural attitudes - which we can find in Japan. The Japanese work ethic are built upon the following points [71-73]:

- *“Workers are highly motivated to seek constant improvement upon that which already exists. Although high standards are currently being met, there exist even higher standards to achieve. “[72]*
- *“Companies focus on group effort which involves the combining of talents and sharing knowledge, problem-solving skills, ideas and the achievement of a common goal. “*
- *“Work itself takes preference over leisure. It is not unusual for a Japanese employee to work 14-hour days. “[72]*
- *“Employees tend to remain with one company throughout the course of their career span. This allows the opportunity for them to hone their skills and abilities at a constant rate while offering numerous benefits to the company. “[72]*

The benefits of the loyalty of the employees can have advantages on both short and long terms. To make a good organization with high loyalty is one of the newest challenges in the industrial life today. [71-73]

## 8. Continuous Improvement – Kaizen

The continuous improvement is a tool to identify the new opportunities and weakest points of the production system and eliminate or reduce wastes. Thousands of companies use different types of continuous improvement methods. The most popular tool found in production areas is the Kaizen technique. Only the benefits of Kaizen is not enough - the companies must involve all levels of the employees in the continuous improvement processes. [74-76]

The Continuous improvement (CI) philosophy can be looked at as a formal practice or an informal set of guidelines. Most of the companies use a prior focus on the formal approaches to the project, process and time management. They use dozens of different tools, for example: kaizen, Kanban, scrum etc. These tools can define the ways for the improvement of processes and cost saving opportunities and put them into a standard frame. In these methodologies the continuous improvement is the number-one point. The continuous improvement focuses on the following fields: high customer service standards, reduction of waste, reductions in time, defects and scrap. [74-76]

One of the most popular steps for the companies to improve their business is to reduce the operating costs. The continuous improvement is the ideal tool to streamline the workflows. Efficient workflows save time and money, allowing you to reduce wasted time and effort. The projects with a lot of deadlines and changings are the gold mine of the continuous improvement, these tasks are full of improvement opportunities. [74-76]

Some successful implementations use the approach known as kaizen (the translation of kai (“change”) zen (“good”) is “improvement”). This method became famous from Imai's 1986 book - Kaizen: The Key to Japan's Competitive Success. [74-76]

Key features of kaizen include:

- *“Improvements are based on many small changes rather than the radical changes that might arise from Research and Development” [75]*
- *“As the ideas come from the workers themselves, they are less likely to be radically different, and therefore easier to implement” [75]*
- *“Small improvements are less likely to require major capital investment than major process changes” [75]*

- *“The ideas come from the talents of the existing workforce, as opposed to using research, consultants or equipment – any of which could be very expensive” [75]*
- *“All employees should continually be seeking ways to improve their own performance” [75]*
- *“It helps encourage workers to take ownership for their work, and can help reinforce team working, thereby improving worker motivation” [75]*

The precious points are the series of tactical steps of the continuous improvement. Furthermore, the strategic steps or elements included in the process increase the value of the delivery process output to the customer side. Furthermore, they improve the flexibility of the processes. Kaizen is a tool or technique of continuous improvement in quality, technology, processes, company culture, productivity, safety and leadership, also at manufacturing areas and at service centers too. [74-76]

It must be emphasized that the kaizen system involves every employee in the improvement process. The leaders and the management team encourage everyone to make improvements and suggestions. The continuous improvement has to happen continuously. In some Japanese companies, such as Toyota or Canon, a total of 60 to 70 suggestions per employee per year are written down, shared and implemented. [74-76]

In the practice there are a lot of huge and complicated problems in the shopfloor and in the processes. The engineers and the employees may not have immediate solutions to these problems. Kaizen is based on little ideas and changes - these small steps must be followed in order to improve productivity, safety and effectiveness while reducing waste. [74-76]

In summary: Kaizen is a Japanese improvement technique that we can use at home or in the business life. Kaizen includes dozens of social activities, like idea management system or any other human resources programs. The concept of Kaizen can be applied in every aspect of daily personal life. In the business life Kaizen contains many of the components of Japanese businesses that have been seen as a contribution to their success: quality systems, automation, suggestion systems, just-in-time logistic, Kanban and 5S are all included within the Kaizen system of running a business. The Kaizen involve the training materials and the supervision that need all of the employees to achieve a better standard, maintain them. [74-76]

## 9. Deming circle – PDCA circle

The PDCA (Plan, Do, Check, Act) is a simple tool to improve and check our activity. It is a repetitive four-stage model for CI<sup>7</sup> business. PDCA model is also known as the Deming circle/cycle/wheel, Shewhart cycle, control circle/cycle, or plan–do–study–act (PDSA). Dr. W. Edwards Deming shown in Figure 9. was an American engineer, statistician and management consultant. Deming is often considered the father of modern quality control (QC). [79-81]



*Figure 9.: Dr. W. Edwards Deming [77]*

The PDCA method is implemented to improve the quality of products and the effectiveness of the production or other processes in the factory within a higher-level life-cycle management, human resource management, supply chain management and also for other business processes. [79-81]

Deming laid the foundations of what nowadays are known as Total Quality Management (TQM) and ISO quality standards. Deming himself credited Walter Andrew Shewhart as the creator of the cycle, however. Shewhart was an American physicist, engineer and statistician, who is often considered the father of statistical quality control. [79-81]



*Figure 10.: PDCA circle [78]*

<sup>7</sup> Continuous Improvement

TQM processes are often divided into the four sequential categories: plan, do, check, and act (Figure 10.). [79-81]

Here's an example of how PDCA is broken down in TQM [79-81]:

- Plan: Define the problem, collect relevant data and information, try to find the root cause of the problem, use problem solving techniques
- Do: Develop and implement a solution, define indicator to check the effectiveness of the action
- Check: compare the before and after data with each other.
- Act: Document the results, make notes, inform your organization and employees about the outcome of the development

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## 10. Poka Yoke

Poka Yoke is a mistake proofing tool what is very popular and important for the production as well as for maintenance engineers. This simple method developed out of the Toyota Production System with the help of Jidoka and automation. Under this definition we mean those pieces of equipment, tools or machine parts, which are so simple and often inexpensive, which prevent defects from being made or highlight them, so they are carried further in the process. These tools can be very useful in the daily engineering life. [82-88]

The father of the Poka Yoke was Shigeo Shingo (Figure 11.). He wrote the definitive works on these techniques, but important to know: he is not the one who invented this idea. [82-88]



*Figure 11.: Shigeo Shingo [84]*

The idea and a demand about mistake proofing came from the old time, before the birth of the lean philosophy. The humble three-pin plug for instance had several designs created in the early part of the 20th century, long before anyone heard of Poka Yoke. [82-88]

Originally many people called the technique fool-proofing, however this was clearly derogatory towards the people using the device, while the best employees can also make mistakes. Shigeo Shingo made a difference between mistakes which in most cases are inevitable and defects which manage to get through the system and reach the customer. Poka Yoke seeks to prevent mistakes from becoming defects. [82-88]

Shigeo Shingo saw quality control as a three-level hierarchy of effectiveness [82-88]:

- Judgement Inspection – Inspectors Inspect
- Informative Inspection – Use of SPC<sup>8</sup> to monitor the process conditions

<sup>8</sup> Statistical Process Control

- Before the fact – Poka Yoke

The least effective method of quality control is to use high number of inspections. If we would like to make system with a good efficiency, we have to use a high level automation and Poka Yoke devices to prevent the failures and defects without humans or operators. [82-88]

Lot of failures come from the human side. It is the weakest point of quality control if we use human resources for inspection. People often fail to observe problems, the work can be repetitive, the shifts can be long, they can be tired, sick or they just have a lot of personal problems which they cannot leave outside of the factory. However, that does not mean that operator inspection should be dismissed as being of no value or being incorrect. We can use machine operators or quality assurances to perform these inspections, but in this case, we get a high risk, thus it is not the best way to avoid the failures and mistakes. [82-88]

A small test was developed by the American Society for Quality, which demonstrates how effective a 100% inspection can be. In this test people have to read a paragraph and while they do so, they must count the number of times the letter “f” occurs; ~~The answer is at the bottom of the page.~~ It turned out that most people would not get the right answer; their results will vary between about 30 and 60 letters “f” is in the paragraph having missed letters or double counted. [82-88]

As we see the human inspection is ineffective. Just consider a process in which inspection is 90% effective for each operator. *“If 1000 defects are passed by the first operator he will miss 100, but of these 100, the next operator will only miss 10 and the third just 1 at 90% per operator efficiency. So a number of linked processes with each operator inspecting the quality of work can still be effective in removing defects; although not the best or most reliable.”* [88]

We can overcome the inefficiencies of inspection through the use of automatic devices called Poka Yoke, these pieces of equipment do the following [82-88]:

- Not accept a defect for the process
- Not Create a Defect
- Not Allow a Defect to be passed to the next process

They do this in a lot of different ways - we can find the following types in practice [82-88]:

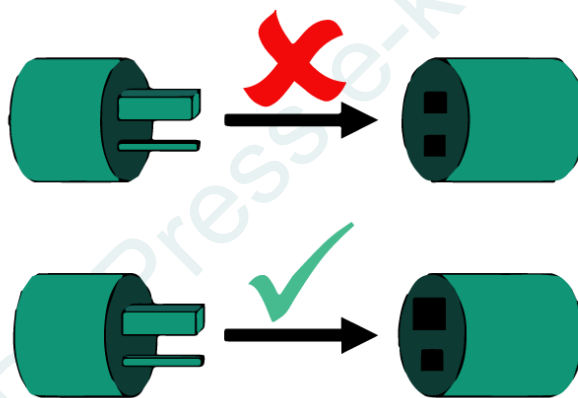
- Control – take physical action or tool to avoid a defect
- Warning – use sound an alarm or light up to warn about the failure

The control type Poka Yoke is very popular in production system. These tools physically reject an under or overweight product or parts with wrong shapes and dimension. These Poka Yokes can use sounds, lights or they can stop the production lines. [82-88]

They can then be further classified into the following three types [82-88]:

- Contact
- Fixed Value
- Motion Stop

The contact type Poka Yoke (Figure 12.) is the simplest. It helps to the devices which have physical shapes that are used to prevent the use of incorrect components, e.g. pins that have to fit into holes from previous operations and so on. They physically make contact with the product and highlight when a mistake has been made or physically prevent the mistake. The easiest examples can be the three-pin plug fit or the sim card in your smart phone, which can only be fitted one way into your phone. [82-88]



*Figure 12.: Contact type Poka Yoke [83]*

The third type of Poka Yoke is the fixed value Poka Yoke. This method uses physical and visual methods too. These properties help the solutions to be available in the right time with the right quantities, it is sometimes combined with contact style sensors for a better and safer operation. The good example is the egg-tray style container. It creates better operation conditions, while the process is not relying on the operators to measure from a larger box or containers. [82-88]

These types of Poka yoke devices ensure that the correct number of steps have been taken and possibly also the sequence of steps. The Poka Yoke devices must be inexpensive, simple, easy to

use. The engineers have to design tools without high costs. Important question during the Poka Yoke design: how much will a defect reaching the customer cost you? [82-88]

The Poka Yoke is one of the most important effective tools to avoid failures and defects in the production system. Thanks to this technique the defects cannot reach the customers and it can contribute to the basis of the lean manufacturing and to implementation of the nowadays most popular maintenance tool called Total Productive Maintenance (TPM). [82-88]

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## 11. The Seven Wastes of Industrial Processes

The seven wastes of industrial processes are what we would like to avoid or remove from our processes. In the practice we know seven wastes, but a lot of company often forget maybe the most important type of waste: the human knowledge and experience. [89-93]

The Seven Wastes of Lean Manufacturing are the following [91]:

- Transport
- Inventory
- Motion
- Waiting
- Over-Processing
- Overproduction
- Defects

This chapter contains sub - chapters and paragraphs with a deeper explanation and examples about these wastes. However, the most important thing is: how can we detect them? [89-93]

The first thing: how can we remember the seven wastes. The operators and employees have to know the names of the wastes but in their daily life they have lot of things to do. We know a couple of Simple Mnemonics that we can use to help employees remember the 7 Wastes. The first is to ask yourself “Who is TIM WOOD?” [91]

TIMWOOD [90]:

- Transport
- Inventory
- Motion
- Waiting
- Over Processing
- Over Production
- Defects

TimWood comes from Standard-Cooper in the UK. It is now probably the most recognized way of remembering the seven wastes. Another alternative name can be the „Wormpit“. [91]

## WORMPIT [91]:

- Waiting
- Over Production
- Rejects
- Motion
- Processing
- Inventory
- Transport

Both words are useful in the practice, these words can help your organization to memorize the seven wastes. It can be also very useful during different training where you have to speak about the wastes or you have to teach lean principles. [89-93]

In the first step we have to understand what is waste exactly. Maybe the simplest sentence about it is the following: “Something that adds no Value.” We can ask: What is Value? The value is something what can make the product better and put it closer to the customer demands. For example: the customer pays for the leather seats, so these kinds of seats are added values because the customer wants it. On the other hand, the quality inspection does not create value, because the customer does not care our process uncertainty. So, the customers are not be very happy if they have to pay for any action or processes what do not add any values for them. [89-93]

Another good example can be the bill in a restaurant. You do not want to pay for the meal that was not delicious, or the service was a catastrophe. But from the point of view of the restaurant it is a waste if you do not pay. Why? The restaurant had to buy the ingredients, they had put energy into the preparation of the meal, they had to give a salary for the cook and etc. If you would like to buy a hammer you do not want to pay for the lunch break of the machine operators, in other words you just would like to pay for the hammer, not for the wastes of the company. You have to pay these wastes from your own wallet! It can be very painful. On a long term a lot of wastes can cause losses for a company or business. [89-93]

So now it is clear why we have to eliminate or minimize the wastes in our production and processes. If you have a lot of wastes in your production, you can ask lower price for your products. If you lose customers or your company will get a bad reputation on a long term your company will lose more and more customers. The most important way to get more profit or increase your profit is to

reduce your wastes - it means that you have to eliminate all of the wasters from your process and services. [89-93]

If you would like to improve your profit in your company, you have to find all kinds of wastes in your processes. Every customer wants their delivery in the right time, right quantity and in a right quality. It is important for the practice, so we know seven plus one wastes. [89-93]

The following paragraphs we describe the wastes that you have to eliminate in your company! [89-93]

### 11.1 The Waste of Transport

The transportation is a movement of materials from point to point. It can be a waste (usually) if it adds zero value to the finished goods. Sometimes the transport is a necessary point of technological processes, for example: heat treatment process. As we discussed in the previous chapter this is what your customer does not want to pay for. In the most cases transport adds no value to the products. But the movement is necessary in a production, just think about conveyors or fork lifts or when we have to move products and raw materials between production lines or factories. The waste of the transport can make a lot of extra costs for your plant. You need people who operate the equipment, you have to buy expensive equipment and you have to pay for the other additional costs of this kind of machines and equipment. [89-93]

### 11.2 The Waste of Inventory

You have to use different types of inventory systems in your production, that costs money, but you can optimize it from the cost side. The question is why? The inventory is very important - in some cases you have to use a high level of stocks if your business requires it, for example: you can guarantee the delivery in 48 hours for all over the world. It is a service from your side and you can use big inventory level. But in the practice the companies would like to eliminate the inventories in the production, also from the area of raw material and finish goods and they try to minimize them in the field of work in process (WIP) stock. The inventory costs can yield many further costs: you have to use logistic operators and other logistic equipment, the warehouses need a building, you have to use shelves etc. All of the equipment need space! The big warehouses and inventories can generate the waste of transportation. We have to see the connection between the different wastes. [89-93]

### 11.3 The Waste of Motion

The next waste is the unnecessary motion. These motions can be movements of people, machines or products. These motions are not as small or easy to perform, for example: bending down to pick up heavy object from the floor. On a long term it causes stress. Another example is to ship the products between two workstations or machines. It is a similar property to the waste of transport. The waste of motion costs a lot of time and causes a high stress for the employees if they have to make pointless and tiring motions in their daily activity. [89-93]

### 11.4 The Waste of Waiting

The waste of waiting is what everybody can feel in his or her daily life too. Nobody would like to wait or stand in a wrong line in the shops or post offices. We can find the waiting problem in production areas too. The waste of waiting is very important for the production and the maintenance team as well. As it shown in the previous chapters we can find a lot of unexpected failures in the system and machines. If the machines stop the maintenance team have to repair it as soon as possible. The production does not have time to wait. They have to produce the product otherwise the company can lose customers. [89-93]

### 11.5 The Waste of Overproduction

The overproduction is a very dangerous waste. In this case your customers demands are not clear, and your processes work poorly. The overproduction leads to another waste, the high level of inventory. Just think about that! You have to put your products somewhere if you cannot sell them. Another dangerous aspect of the overproduction is the cost of the production processes. If you would like to get a finished product you have to put a lot of energy and money into it. If you can find overproduction in your company, that means that your just in time system does not work. [89-93]

### 11.6 The Waste of Over processing

The waste of Over processing is where we use inappropriate techniques or oversize equipment. During this waste we perform a lot of processes that are not required by the customers or by the management. It means that we lose time and money for the company. The easiest lesson is the example of the mega machine. This machine is fast, but it makes a lot of complication in the other processes and supporter areas. The basic lean principles suggest having small appropriate machines

instead, and if possible do not buy the most expensive huge machines - „the small is beautiful”. [89-93]

## 11.7 The Waste of Defects

The definitions and the explanations of these wastes are very easy to understand, but not easy to find them. The wastes and defects can reach your customer. The most critical failures are the quality errors. If your customer gets defected parts he or she can send a quality complaint and you can lose business. The wrong maintenance has an effect on the quality of products. To avoid this waste, you have to use Poka Yoke tools, automation and improve your machines and maintenance program too. [89-93]

## 11.8 Additional wastes

In the daily life we always speak about seven wastes. Most of the companies forget the main principle of lean, and maybe the key for the success. It is the waste of talent. The machine operators, maintenance technicians, engineers and other employees have broad knowledge and experience in their work and daily routine. If you would like to improve your processes and your organization, you have to use these experiences and knowledge. You have to involve all of these people to develop your company and build a better future for your company. These people live in the processes and they see where are the weak points in your system. This is the seven wastes plus one. Summarized, we know eight wastes in practice. In real life there are a lot of human resource tools what you can use to get these ideas from your employees. [89-93]

After the waste detection you have to eliminate them the from your system. You can use a variety of tools, lean tools, techniques or methods. Important to know that your focus should not be to identify and remove waste. Instead you have to use lean principles to define the values in your process and your customer demands. If you will see the value, you can start creating a perfect process flow. The redesigned processes automatically help you to eliminate or minimize the wastes. The processes will work with a higher efficiency and it will be more valuable. [89-93]

The development activity has to be made continuously. You have to use lean principles, PDCA circle and other continuous improvement methods. The customer demand, the external and internal processes are always changing. If you would like to save your company money or improve your department competitiveness, you have to eliminate the seven plus one wastes and always use continuous improvement techniques. [89-93]

## 12. Muda, Muri, Mura - Toyota 3M model

We know three another sets of wastes. The idea comes from Toyota where they developed their system in order to eliminate the three enemies of processes, which are the following: Muda (waste), Muri (overburden) and Mura (unevenness). The previous chapter contains a lot of details about Muda. As written above we know eight different types of wastes, these are the following: transport, inventory, motion, waiting, overproduction, over processing, defects and waste of talent. Simply taking out the Muda sometimes does not work in the practice. Usually, there is a reason why the Muda is there, and this reason often has to do something with the other two enemies: Muri and Mura. This means the three enemies of lean show relationship between each other. [94]

The three waste sets can be found at production areas and at office processes too. The office processes can hide a lot of wastes. The production wastes are easy to see - you can see the unnecessary motions, the high stock etc. In the offices the processes are often hidden inside the computers, servers, mailboxes and IT systems. [94]

The main goal of the engineer to eliminate the three groups of wastes. In a lot of cases it is impossible to eliminate all of them from the processes, for example: you cannot build up your factory next to your customers and suppliers. So, you have to deliver your product and your services, you just try to reduce the time of transportation as you can, but you cannot reduce it by 100%. The situation is similar to Muri. There can always be a time where machines or people have to give that little extra effort or time to make sure the customer demand is fulfilled. There is no problem with this activity if you get extra orders or win a new customer or client. The problem starts when you are expecting these from your employees all the time, until the point where a machine will burn down, or a colleague burns out and leaves the company. The last group is the Mura. The Mura cannot be reduced by 100% either, but we can find good examples in practice. If you have a big various product mix, you have to use different materials and you have to use different technology and process times. Or it is just enough to think about project works, where the projects are different, or in the financial world, where a financial report needs to be delivered at the end of each month. [94]

The following three small paragraphs describe the main properties of the three waste groups. [94]

*“Muda, waste, can be defined in eight types, 7 defined by Toyota and ‘non-utilized skills’. These are (again): transport, inventory, motion, waiting, overproduction, over processing, defects and*

waste of talent. As Mnemonic device, the first letters of these wastes form the acronym downtime. There are numerous tools available to identify and remove waste from your process, which include Poka Yoke, Kanban, Takt Time, SMED and One-Piece flow. In the article each of the types of waste are described and linked to tools which can be used to eliminate them systematically.” [94]

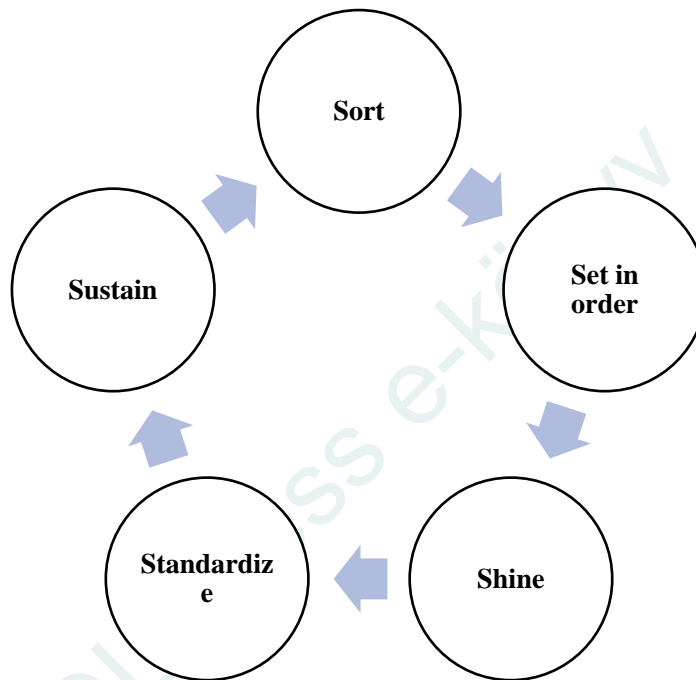
“Muri, overburden, can result from Mura, and from removing too much Muda (waste) from the process. When operators or machines are utilized for more than 100% to finish their task, they are overburdened. This means breakdowns when it comes to machines and absenteeism when it comes to employees. To optimize the use of machines and make sure they function properly, preventative- and autonomous maintenance can be implemented. To prevent overworked employees, safety should be the focus of all process designs and all standard work initiatives.” [94]

“Mura, unevenness, can be found in fluctuation in customer demand, process times per product or variation of cycle times for different operators. In production environments with low-volume, high product variation, flexibility is more important than in high-volume, low-product variation environments. When Mura is not reduced, one increases the possibility for Muri and therefore Muda. Mura can be reduced by creating openness in the supply chain, change product design and create standard work for all operators. “ [94]

### 13. 5S

One of the most important tools for engineering in shopfloor or on maintenance sites is the 5S (Figure 13.), which is also a basic lean principle. The 5S is built up from five points: Seiri, Seiton, Seiso, Seiketsu and Shitsuke. [95-108]

5S is a very simple but powerful tool. It has strict rules that you and your organization have to follow. These rules help to organize your workplace, workstation, clean and safe with a good ergonomomy. The 5S helps to build up an easy to use visual management system. The visual management tools help to introduce a standardized working process in your organization. [95-108]



*Figure 13.: 5S circle [95]*

The standard work provides you a stable foundation of all of your development and improvement processes and you also provide a professional visual workplace. [95-108]

In addition to standardized work which provides you with a stable foundation to build all of your other improvements through implementing Lean Tools, you also provide a highly visual workplace. The 5S can make visible the problems as soon as possible. The 5S projects are a very important team work or team project. You have to involve those people who are working on the shopfloor. You have to discuss the new standards and tools of the processes at the shopfloor. Very important to avoid to use those tools which came from any outsider without any experiences about the current situations. [95-108]

Important to know: the 5S methodology is walking hand in hand with the Total Productive Maintenance from the Toyota Production System. Hundreds of 5S aspects can make a good basis for the TPM system. In this way, you can make ergonomic and efficient work places, tools and machines. The good ergonomics and the cycle time reduction can make a workplace with a better efficiency and with a higher safety too. [95-108]

Frank Gilbreth was the first who showed the importance of the ergonomics. He made a study about the improving the ergonomics of the bricklayers working. He reduced the number of the individual movements required and increased the hourly output from 120 to 350 bricks per hour. [95-108]

The 5S is a strict methodical solution to improve your organization, processes and workplaces. This philosophy can change the root of the way of the daily working. The 5S contains five easy steps. These five steps named after different Japanese terms, which are beginning with letter „S’. This is the reason why we called this method 5S. [95-108]

These five points are the following (also with the English name) [95-108]:

- 5S Seiri; Sort, Clearing, Classify
- 5S Seiton; Straighten, Simplify, Set in order, Configure
- 5S Seiso; Sweep, Shine, Scrub, Clean and Check
- 5S Seiketsu; Standardize, Stabilize, Conformity
- 5S Shitsuke; Sustain, Self-discipline, Custom and Practice

Nowadays the safety is very important for every production company, offices or service centers. In the literatures much has been written about a bit more than 5S - it is the 6S. The first five points are similar to the ones in the 5S method, but this methodology includes one more tool, namely the safety - the new important tool is thus the 6S. [95-108]

We know a lot of different methods to memorize 5S method. Lot of business organizations came up with non Japanese equivalents. These new designations can help to use 5S from a new approach. 5S is also known in some fields as 5C, with the “S” words replaced by [95-108]:

- Clearing,
- Configure,
- Clean and Check,
- Conformity
- Custom and practice.

or:

- Cleanup,
- Arrange,
- Neatness,
- Discipline, and
- Ongoing Improvement.

### 5S Seiri or Sort

Sort is the first step in 5S. Reducing the risk of hazard by going through all the tools, materials and equipment in the work area and organizing them keeping only the important items. Unnecessary items are either stored or discarded. [95-108] [110]



*Figure 14.: Seiri/Sort [110]*

### 5S Seiton or Straighten / Set in order

Team members gather to make the workplace more visually instructive. It is done by placing tags on equipment and tools, keeping specific tools within visuals and in a specific zone around the workplace to make it easier for others to obtain it. Also, to establish border lines for tools to not be placed in other areas to prevent hazards and to keep the workplace well-organized. [95-108] [110]



*Figure 15.: Seiton/Set in order [110]*

### 5S Seiso or Sweep / shine

This step is important to the work area because it deals with the appearance of the facility. It includes three activities [95-108] [110]:

1. cleaning the workplace.
2. maintaining its appearance.
3. keeping it clean by using preventing measures.

This is done by removing dirt, dust, fluids, and debris. Maintenance personal are equipped with cleaning supplies in their tool boxes which includes special solutions that is adequate to remove all contaminates. Personal are required to clean equipment, tools, work surface, storage areas, floors, lighting and anything that could be considered as hazardous or inappropriate for the work place. [95-108] [110]



*Figure 16.: Seiso/Shine [110]*

## 5S Seiketsu or Standardize

During this step, team members gather to identify and establish an improved workplace as a standard. This step is well used in administrative departments more than the maintenance department. The team is required to label items and to make it easier to identify old and new material. This is done by color coding, flow charts, checklists, or by simply labeling the material to help support a unified approach to a better and more appropriate workplace. [95-108] [110]



*Figure 17.: Seiketsu/Standardize [110]*

## 5S Shitsuke or Sustain

The purpose of this step is to ensure that the implementation of S1, S2, S3, and S4 by the employees' is maintained. An auditing process set by the management should be established to further ensure that the employees understand that maintaining an organized workplace is the company's top priority. The audits conducted by the management should be done on a routine and scheduled basis to ensure that the implementation is being properly cared and maintained. Plus, the audit gives a good opportunity for the employees to provide ideas and suggestions that improves that status of the workplace. [95-108] [110]



*Figure 18.: Shitsuke/Sustain [110]*

The 5S implementation looks like very easy but sometimes the industrial experiences show a difference to the previous statement. If you would like to implement successfully a 5S system, you will have to organize continuous training programs for the employees and the whole organization. It ensures that everyone knows the rules and importance of 5S and how it fits into your company life. [95-108] [110]

The standardization is the main part of the 5S and also of the lean principles. It is the most important and powerful aspect of the engineering life but in the practice sometimes it is forgotten pillar of the daily industrial life. The documentation of the best practices of the standardization can make the ideal base for the continuous improvement tools and kaizen. If we have an unstable process, we cannot make any developments. The improvement of the standardized works is a never-ending story. [95-108] [110]

The standardized work has three main elements [95-108] [110]:

- Cycle time, which is the rate at which products must be made in a process to meet customer demand (inner and outer customer too)
- The precise work sequence in which an operator performs tasks within cycle time
- The standard inventory, including units in machines, required to keep the process operating smoothly

It is very important to collect and record data from the shopfloor on forms. These forms are very useful for engineers and management to improve and control the processes plus the operators can make any changes in their daily routine. In practice a lot of workshops have to solve these kinds of standardization issues. The workshop starts with data or information record, then the team have to discuss the wastes, mistakes and the misunderstanding points in the processes. [95-108] [110]

The standardized work has a lot of benefits. It includes standard documentations, tools all over the company. The rules of standardization give discipline to the company culture. It is also a very important learning tool, it supports audits, because the processes are clear and easily visible for the auditors. It also facilitates the problem solving techniques and involves the operators, technicians and the whole organization to improve the processes and their knowledge, all in accordance to the lifelong learning philosophy. [95-108] [110]

## 14. Andon

The Andon or Andon light is a very important marker system in the production. It can show management, maintenance or other employees a quality process problem or any other machine problems in the process. The main device of the Andon is a signal light (Figure 19.), which can indicate which workstation has a problem. We know two ways to activate the system. The first is manually, when the workers use a button or a pullcord. Alternatively, the system can activate itself automatically. In the practice, the automatic activation is widespread. The system may include a means to stop production, so the issue can be corrected. The modern versions of Andon systems use audio and text alarms as well as different types of LCD displays. [111] [112]



*Figure 19.: Andon light [111]*

The Andon light has three different colors. It works similarly to the traffic lights. The green light shows that everything works fine, the yellow shows that the machine is stopped (for example: lunch break), while the red light shows a defect or a failure in the system. [111] [112]

The Andon system is an important element of the Jidoka quality control method. These techniques are part of the Toyota Production System and nowadays they are very popular in the modern factories and they are part of the lean approach. The Toyota was the pioneer of these techniques. [111] [112]

The Andon system gives a possibility of decision and a responsibility about the product quality. They can stop the production and when they find a defect they can call for assistance immediately. If the alert is false, they can let the process continue and the production can go forward. This is the manual activation of Andon system: if the operators find material shortage, defects, tool

malfunction or any other safety problem. The work is stopped until a solution is found. The alerts can be logged into databases - these Andon alert datas can be key performance indicators, which are important to analyze in order to understand the reasons of the machine stops and quality defects. [111] [112]

The system indicates where the alert was generated, and it can give a description about the trouble. The modern Andon systems can include text, graphics or different audio alerts which help to find the infected machine or production lines. The audio alert can use different coded tones, to the various alerts. Or the management can use prerecorded verbal messages. It is very helpful for the machine operators and the maintenance technicians, because they will know the weight of the failures. [111] [112]

W. Edwards Deming developed the basic concept of the non-management worker. Thanks for these concepts the machine operators can stop the production line if any quality failures detected. Deming was the main pioneer of this method and this method is very popular in the modern industrial life. Deming had a big inspiration on a Japanese post-war economic miracle of 1950 to 1960. Thanks for this work, the Japan economy is the one of the biggest economy in nowadays. [111] [112]

The Andon word originated in Japanese manufacturing and production companies, in English it is a loanword from a Japanese word for the paper lantern. [111] [112]

## 15. Jidoka

Jidoka is the forgotten pillar of the Toyota Production System and of the lean manufacturing. It is the most important tool of lean, which can help to achieve a true excellence in process and quality. The focus of the Jidoka is the quality. The company without excellent product or service quality cannot survive the ruthless industrial competition. The Jidoka is the ideal tool (or method), which can help to keep alive the company or to become a market leader. [113] [114]

The inventor of the Jidoka was Sakichi Toyoda in 1896, Japan. He used a simple device that could stop the shuttle on an automatic loom if the thread broke. What does it mean? *“It means that it prevented the machine from not only creating defects but also alerted the machine operators to a problem. This meant that one operator could now operate several looms rather than have to stand there watching just one in case something went wrong. This principle became known as automation with a human touch.”* [113] [114]

The sale of the patent for this invention to a UK mill provided the funding so it allowed the Toyoda family to fund the creation of a new business, Toyota. The new principles which were applied to machines with automation was just the first step Taiichi Ohno applied them to the whole process. [113] [114]

The Jidoka is built up from four simple steps that you can follow in the practice [113] [114]:

- Discover an abnormality
- STOP
- Fix the immediate problem
- Investigate and correct root cause

This principle is just not a simple automation tool, Jidoka itself (and the philosophy of Jidoka as well) is visible in every aspect of lean philosophy when your organization would like to start or implement it. You have to build the quality into your process, you do not have to make inspection and measurements at the end of your production - it would be a waste. But you have to know: the inspection still has a place in the Toyota Production System, and despite what people think about it, the inspection can be a powerful solution of preventing defects reaching the customer. [113] [114]

The good lean companies follow that each employee has not only an authority, but the requirement to stop the machines and processes if they detect any failure or mistake. It is a good way to avoid problems and break downs and it can provide a way to find a solution to the problems. This step is sometimes forgotten by a lot of western companies. They fear a drop in the production numbers and the fury of the owners and of the management. The western companies always would like to get a result as soon as possible, but they always forget the more than sixty years old advantage of the Toyota. [113] [114]

This hurry-scurry and fear can undermine the lean philosophy and all of the values of lean manufacturing. Jidoka does not just stop the process, the Jidoka can put the problems into highlight, correct it, fix it and find the root cause of your problems and try to avoid them or eliminate them from your system. [113] [114]

In the beginning of Jidoka implementation you will meet a lot of short line stops. It will be very stressful for your organization. During these small stops you have to find and eliminate the problems. This improvement process results in fewer line stops, makes you to have to be patient. It is sometimes a long-term strategy, i.e. you will not get results from the first time. It is always important to find the root cause of the problems! [113] [114]

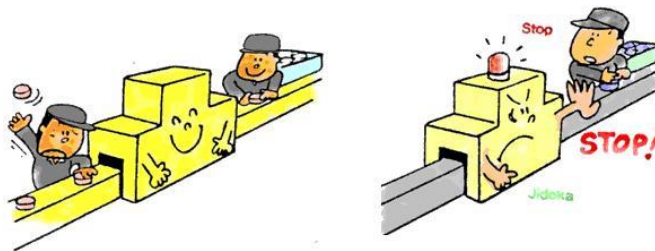
At companies like Toyota the machine operators can stop the production lines or machines if they detect a problem. They push a button and turn on the Andon system manually or it can work automatically. The Andon light or board gives a feedback for the production supervisor or for the maintenance team, who will immediately rush over to help solve the problem. If the problem is easy to solve they can restart the machines and production lines and the life goes on. Otherwise if they find a critical problem they ask a support from the right department. [113] [114]

Nowadays (2017) the machine design and the automation walk hand in hand. The technology has a lot of new brands and tools, just think about the Industry 4.0 chapter. Thanks to this huge development in the automation field these devices now are cheaper than during the previous twenty or thirty years. [113] [114]

The management have to change the point of view about the role of the supervisors and machine operators. They have to have authority and responsibility to stop the production when they find a failure in the system. It is important to train everyone for using appropriate problem solving tools, which enable one to investigate the root cause of the problem. The authority and responsibility are not enough, you also have to ask for a good documentation process that you have to keep up to

date with the new changes. You have to communicate these documents and you have to spread them within your organization. [113] [114]

The Jidokas' first step is to detect any abnormality - automation machines use simple sensors to detect problems. If they find any failures, they stop the process and “show” the problem for the operators (Figure 20.). For line stop the operator has to find an abnormality as soon as possible, then he stops the line or machine or highlights the problem on an Andon board or Andon light for all to see. [113] [114]



*Figure 20.: Funny picture about Jidoka [114]*

Other lean tools can also be useful to investigate the problems, for example visual management methods or 5S. With 5S we can identify the place of the tools and equipment. If we see that the things are not in their allocated place it means an abnormality. Where are the tools? Why are they missing? Why are they in a wrong stock? etc. Other logistic tools, like Kanban are also able to highlight the problems. [113] [114]

The Total Productive Maintenance (TPM) also contains a lot of useful techniques. You can replace the shield or covers of the machine with transparent covers. It lets your see the machine problems clearly. You can use Kamishibai boards to schedule maintenance and other tasks - if cards are not turned we can see at a glance that we have problems. [113] [114]

This chapter contains the basics of Jidoka. It is explained why we have to use it and why it is important for the management. The Jidoka is very important in a lean production system, it can display a lot of production problems. It is very important to involve all of the employees of the production to develop the local Jidoka system. You have to transfer authority and responsibility for the machine operators or the production shift supervisors. The leaders need to keep in their mind: they have to keep open their eyes during the factory walks and always try to find the wastes, problems and they have to try to solve the problems with a Jidoka principle. [113] [114]

## 16. Lean Maintenance

Lean maintenance is a proactive maintenance activity that plans and schedules maintenance activities through Total Production Maintenance methods. It is using maintenance tactics established with the assistance of reliability centered maintenance (RCM) decision logics. It is applied by teams using the 5S method. Lean manufacturing is a production method that considers the expenditure of resources for any goals other than the value of quality for the customer to be wasteful. Lean is a variety of tools that is used to eliminate waste, that is done by reducing the time lost on machine failures. As waste is removed and eliminated, the quality improves while production time and costs decrease or stay the same. [109] [110] [115-121]

Lean Manufacturing aims to discard three types of waste within an [109] [110] [115-121]:

- Processes that do not hold any value to the need of the customer.
- Insufficient processes.
- Abnormalities in production.

In an organization, which contains a lean manufacturing methodology, it aims to [109] [110] [115-121]:

- Schedule production according to orders rather than to stock inventory.
- Batch sizes are kept to a minimum.
- The operation runs smoothly and does not get interrupted.

Unscheduled downtime of machines is a serious issue in a factory, plus the time taken to repair these unscheduled repairs abrupt the flow of work. Thus, affecting the time needed to deliver the products requested will affect costs and budgets that the company is not scheduled for. Lean maintenance approach aims to prevent unscheduled downtime for the machines. This is done by reducing or eliminating the cause of the machine breakdowns. [109] [110] [115-121]

Advantages and disadvantages of Lean Maintenance [109] [110] [115-121]:

- Cost saving: Manufacturing quality products upon ordering only will keep cost to a minimum.
- Time saving: The use of efficient machines for producing large amounts of products reduces the time.

- Energy saving: Lean manufacturing suggests that it will use more energy-efficient machines and equipment. This will save time and thus save energy consumed. This will save a lot of fuel and electricity.
- Easier monitoring: Using a WinMan ERP program as a resource planning solution will close all wastage gaps. It will monitor the company's operation easily.
- Customer satisfaction: Lean manufacturing will save the time to suit the needs of the customer by producing quality products that will satisfy the customer.
- Business continuity: With costs and time saved, the sustainability of the company will surely increase.
- Good working environment: Generate a pleasant atmosphere for employees to work.

Disadvantages [109] [110] [115-121]:

- Negative awareness by employees: Lean manufacturing suggests to use less manpower in order to save costs and reduce time. Workers may get frustrated.
- Unstable economy.

## 16.1 Relationship between Lean Maintenance and Total Productive Maintenance

Total productive maintenance is related to Lean maintenance in a way that it is considered the foundation of Lean maintenance. It is an initiative for improving the reliability and effectiveness of equipment. Total production maintenance is built on the concept of team work in the facility that includes every position in the organization, from the executive manager to shopfloor workers. All are working in conjunction with one another to keep the organization in flow and without flaw. [109] [110] [115-121]

Total productive maintenance is one of the tools used in Lean maintenance and it is considered to be one of the most difficult tools to be used and implemented in companies for two reasons [109] [110] [115-121]:

- A total production maintenance implementation needs a great amount of culture change within the organization almost immediately.
- Among all departments in the organization that has potential lean process improvement, the maintenance department is one of the smallest concern within the organization.

## 17. Total Productive Maintenance

Total productive maintenance is an optimal maintenance program philosophy for the function of maintenance and repair of machines, equipment and plants. The aim of the total production maintenance program is to increase production, at the same time to increase its employee morale in order to better satisfy them in the workplace. Employee motivation helps to keep production and quality at a high level. Other than increasing employee satisfaction, total production maintenance's goal is also to keep sudden breakdowns of machines and equipment to a minimum or to possibly prevent them. It focuses on maintenance so that it has become an important part in the industry world. [109] [110] [115-121]

Total Productive Maintenance is stemming from three words below [109] [110] [115-121]:

- Total: considers all situation aspects and includes everyone employed in the organization.
- Productive: signifies the perfection as production goes on without failures and breakdowns.
- Maintenance: Equipment which is handled by operators in good condition, repair, clean, lubricate, with the willingness to spend time caring for it.

Total productive maintenance is a general and complete method for maintaining equipment that aims for a perfect production by achieving [109] [110] [115-121]:

- No breakdowns of machines and equipment.
- No equipment defects.
- Creating a safe environment and keep accidents to a minimum or to prevent it.

Total productive maintenance uses preventive and predictive maintenance as its primary tools to maximize the equipment efficiency in terms of operation. Implementing total production maintenance programs creates a good working environment in the workplace and encourages employee to share responsibility of the workload and get more involved. When implemented in the right environment, it can help improve productivity by increasing uptime, decreasing downtime, preventing defects and breakdowns, and increase employee morale. [109] [110] [115-121]

### 17.1 History of Total Production Maintenance

Total productive maintenance's origins can be dated back to 1951 when preventive maintenance was presented in Japan. Though, the idea of preventive maintenance was taken from the United

States. In 1960, the first company to introduce preventive maintenance was Nippondenso. [109] [110] [115-121]

In some books and articles, we can find the following definition of Preventive Maintenance: *“Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level.”* [121]

Preventive maintenance is a type of maintenance that uses a periodic program to maintain and repair machines and equipment. The work is given to the maintenance group, which involves technicians and operators, both working side by side to produce goods using these machines that maintenance group perform the maintenance on. The definite implementation of preventive maintenance differs significantly. Some programs are extremely limited and consist of only lubrication and a few modifications. Comprehensive preventive maintenance programs schedule repairs, lubrication, modifications, and machine assemblies for all plant machinery. [109] [110] [115-121]

Thus, Nippondenso who used preventive maintenance as its primary maintenance concept also included autonomous maintenance to be done by the production operators. The maintenance team dealt with equipment modification to refine and improve the reliability. The maintenance team modified and improved new equipment which led to the prevention of maintenance, thus maintenance improvement and maintenance prevention created predictive maintenance. [109] [110] [115-121]

Predictive maintenance is a type of maintenance that predicts failures by monitoring the equipment for any signs of abnormalities and forming data analysis on the equipment. Using the data gathered, maintenance measures are created to prevent the failures before it happens. [109] [110] [115-121]

Predictive maintenance aims to improve productivity, product quality, and overall effectiveness of manufacturing and production plants. Predictive maintenances goal is to use the equipment's effectiveness to its fullest in order to achieve an ideal life-span of production equipment. [109] [110] [115-121]

Vibration monitoring, thermograph, and tribology are tools that a comprehensive predictive maintenance management program uses to obtain the condition of the operating plant system, thus producing data schedules for all maintenance crew. [109] [110] [115-121]

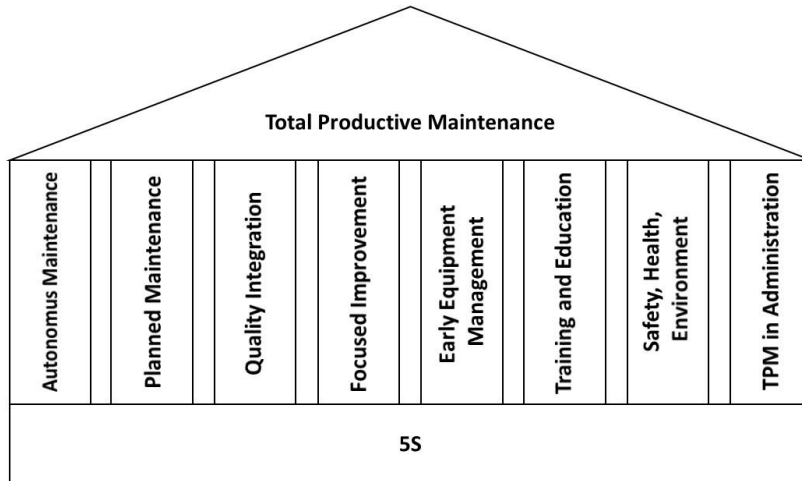
After a while Nippondenso had got their employees involved and participate in extra activity called “quality circles”. That encouraged the employees to take part in implementing predictive maintenance. Based on these facts, Nippondenso received the grand plant prize for the development and implementation of Total Productive Maintenance by the Japanese Institute of Plant Engineers, making Nippondenso of the Toyota group the first company to receive the total production maintenance certification. [109] [110] [115-121]

## 17.2 The Spread of Total Production Maintenance

Total Production Maintenance began its origins in the automobile industry and quickly spread to be an essential part of the corporate philosophy in companies such as Toyota, Nissan and Mazda as well. Consumer industries, appliances, machine tools, plastics, microelectronics and other branches have also been presented to Total Production Maintenance. Process industries followed and began to use total production maintenance as their primary maintenance method for maintaining a good working maintenance environment. A vast variety of process plants such as food, rubber, oil refining, chemical, pharmaceuticals, gas, cement, papermaking, iron, steel, and printing industries have adopted the total production maintenance philosophy over the past few years. At first, total production maintenance was only involved in specific departments directly linked with equipment such as production. However, while other departments were supporting the total production maintenance methodology in production, they soon followed suit and started implementing the methods in their own ways: for example, administrative departments are now applying them to improve their effectiveness in their work area. Total production maintenance, while expanding rapidly in Japan, expanded also to other countries and regions, such as the United States, Europe, Asia, the Middle East, and South America. Companies in these regions have also adopted the methodology and implemented total production maintenance in their facilities to improve and enhance their production and to lower their costs. [109] [110] [115-121]

## 17.3 Bases of Total Productive Maintenance

The approach to Total Production Maintenance was created in the 1960s and consisted of two things, whereas the 5S as its foundations and eight pillars act as supporting activities. [109] [110] [115-121]



*Figure 21.: Bases of Total Production Maintenance [110]*

## 17.4 The Eight Pillars of Total Productive Maintenance

As mentioned, the eight pillars of total production maintenance act as a supporting role for total production maintenance with the 5S as its main foundation. The right pillars mostly consist of proactive and preventive techniques used to further support 5S. The eight pillars are shown in the following table. [109] [110] [115-121]

Table 4.: Improving areas [110]

<b>Pillar</b>	<b>Description</b>	<b>Benefits of Pillar</b>
<b>Autonomous Maintenance</b>	Performing routine maintenance such as cleaning machines, lubrication and daily inspection by the operators.	1- Makes sure that the equipment and machines are cleaned and lubricated. 2- With daily inspection, the operators can detect any abnormalities in the equipment. 3- Operators will be knowledgeable with the equipment and the type of condition it represents.
<b>Planned Maintenance</b>	Failure rate is measured and/or predicted, and maintenance tasks are scheduled to prevent them.	1- Prevents downtime and unplanned shutdown of the equipment. 2- Planned maintenance could be done when the equipment is not scheduled for production.
<b>Quality Maintenance</b>	Perform a root cause analysis check to discard frequent causes of quality defects. Detect and prevent any error in the production process	1- Detects and reduces the error in production. 2- Detecting defects early causes a reduction on the failure costs.
<b>Focused Improvement</b>	Groups are tasked with the continuing improvement of equipment operation	1- Inspires employees to continuously think about new ideas that benefits the organization. 2- the continued improvement of equipment will reduce the failure rate.
<b>Early Equipment Management</b>	Improve and Design new equipment with the knowledge of manufacturing equipment obtained through total production maintenance	1- Employees are more familiar with the new equipment being operated. 2- Maintenance is much easier and simpler due to the familiarity of the equipment by the employees.
<b>Training and Education</b>	Training the employees with the necessary knowledge to accomplish the goals set by total production maintenance standards.	1- Employees develop new sets of skills to help them with their daily tasks and identifying problems. 2- Inspires everyone to work as a team, from the top executive to shopfloor employees.
<b>Safety, Health, Environment</b>	Maintain a safe working environment for everyone in the organization	1- Prevents hazards. 2- Aims for an accident free workplace. 3- Eliminating Health risks that could affect employees
<b>Total Production Maintenance in Administration</b>	Apply the knowledge gained from total production maintenance in Administrative functions	1- Improves administrative operation thus improving plant operation. 2- Eliminates the waste in administrative functions. 3- Faster Performance.

Benefits of Total Productive Maintenance: [109] [110] [115-121]:

- Products are improved through minor losses in the organization.
- Product Quality is improved.
- Unexpected failures and downtimes are reduced/eliminated.
- The total budget cost is reduced due the decrease in losses and other non-value work.
- Organization working as a team, from the top executives to the shopfloor workers.
- Employees gaining new sets of skills to improve and have ownership over equipment.
- Increases employee morale and confidence when working in a zero failure, zero defect and zero accident work environment.
- Improved working environment for the employees.
- Increased plant reliability.
- The continuous improvement by total production maintenance leads to a high working performance and customer satisfaction.

Six big losses of Total Productive Maintenance [109] [110] [115-121]:

- Equipment Breakdown losses.
- Setup and adjustment losses
- Idling and minor stoppage losses
- Reduced speed losses
- Quality defects and rework losses
- Strat-up losses

Table 5.: Steps for implementing total productive maintenance [110]

<b>Implementation phase</b>	<b>Implementation steps</b>	<b>Activities of implementation</b>
<b>Preparation stage</b>	The announcement of total production maintenance by the top management	Declaring the introduction of total production maintenance using seminars, or by a company newsletter, or magazine, or placing it on the notice board.
	Initial Education and campaigning for total production maintenance	Training managers and employees using presentational slides, or camps and other activities.
	Establish groups to promote total production maintenance	Setting up departmental groups for the total production maintenance program.
	Create total production maintenance goals and policies	Benchmark targets and set prediction effects.
	Develop a plan for total production maintenance implementation	Develop a step manual for total production maintenance implementation to be adopted over time.
<b>Preliminary Implementation</b>	The introduction of total production maintenance to partners	Invite suppliers, related companies, affiliated company to introduce total production maintenance.
<b>Total Production Maintenance Implementation</b>	Overall improvement of efficiency in production	Establish a system to improve efficiency in the production department.
	Improve equipment effectiveness	Establish groups to continue improving of equipment effectiveness.
	Develop an autonomous maintenance program	Perform System inspection, diagnosis.
	Develop a scheduled maintenance program	Perform Predictive maintenance, periodic maintenance, improvement maintenance.
	Establishment of training session for improving worker's skills	Educated and killed leaders training workers to develop new sets of skills.
	Develop an initial equipment program management	Develop easy manufactured products and easily handled equipment.
	Create a quality management group	Set work condition and maintenance control without flaws.
	Improving related sectors and departments	Establish a system to improve the efficiency of administrative departments and other related departments.
	Control a safety, healthy working environment	Establish a system for a zero accident and zero pollution action.
<b>Total Production Maintenance Stabilization</b>	Perfect implementation of total production maintenance	Keep maintenance improvement continues. Set new goals and achievements. Applying for PM awards.

## 17.5 Total Productive Maintenance Methods

A full implementation of a Total Productive Maintenance plan cannot be achieved overnight, especially in an organization that does not have total production maintenance as a main function. The time consumed to achieve perfect conditions depends on the organization's size in terms of equipment handling, availability of skilled employees and the number of equipment. A range from a year to three years is required to establish a perfect total production maintenance organization. To do so, a plan is required to properly implement total production maintenance. The key essentials to its implementation are the level of development of awareness about total productive maintenance, classification of issues identified, gathering information and data about losses, the expenditure of human resources and creating groups, identifying and implementing engineering methods, evaluating those methods by analysis and interpretation, and documentation. [109] [110] [115-121]

The method consists of phases, which depend on the type of situation chosen [109] [110] [115-121]:

Table 6.: Total Production Maintenance methods [110]

Method	Phases	Activity
<b>Preventive maintenance</b>	Reduce insatiability of life span of equipment	Use neglected equipment Eliminate defective equipment
	Increase life span	Improve design Eliminate unplanned and unscheduled breakdowns Maintain equipment regularly
	Perform frequent repairs	Identify root causes of failure Plan periodic repair
	Predict the life span of equipment	Performs diagnostics on equipment Do analysis of big breakdowns
<b>Autonomous maintenance</b>	Housekeeping	Basic cleaning Identify causes of problems Lubrication standards
	Inspection	General inspection of equipment Autonomous inspection
<b>Education and training</b>	Basic training	Understand the use of nuts, bolts, screws, etc. Basic training on cleanliness
	Intermediate training	Understand the use of using bearings, power transmission systems, hydraulic, pneumatics and sealing
	Operational training	Training Maintenance methods Use calculations
	Diagnostics	Training in analysis
<b>Startup</b>	1.	Maintain a startup
	2.	Useful analysis
	3.	Maintenance prevention

	4.	Predict and evaluate costs
<b>Maintenance and economic evaluations</b>	1.	Record data
	2.	Reduce analysis Design standards
	3.	Standardization of practices
	4.	Evaluate efficiency

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## 18. Root Cause Analysis

The Root Cause Analysis (RCA) is a popular method of problem solving. It helps to find and define the root causes of the detected problems. Finding or eliminating the Root Cause, we have a good chance that the problem will never come back again. You have to work thoroughly, you have to find the real root cause - it is very difficult, so you have to always work in a team, never alone. Sometimes you can eliminate some factors which occur as the problem, but basically it is just a solution for a short term. The main reason will still be remaining in the system. [109] [122-128]

A very popular method came from the rocket design industry, because they are producing such complex and very dangerous machines. This method is the Kepner - Tregoe analysis from the 1950s. The study was ordered by the National Aeronautics and Space Administration (NASA) in the United States. The name of the method is Management Oversight Risk Tree (MORT). The root cause analysis is an iterative process, an ideal tool for continuous improvement, because it can show the real problem in your process or in your system. [109] [122-128]

In the following two subchapters we will check two basic root cause analysis methods. The reader can find examples what he or she can use in the practice. [108] [122-128]

### 18.1 A Look on Fishbone

#### 18.1.1 What is Fishbone Diagram?

It is known as an analyzing tool, which was invented by Dr. Kaoru Ishikawa, a Japanese quality control statistician. The fish bone is sometimes also termed as Cause and Effect Diagram. It provides a systematic way of analyzing the effects and the causes that might be a cause or contributor to the problem. [109] [124]

#### 18.1.2 Aim of Fishbone Diagram

The diagrams have a purpose to help the teams in figuring out the critical and potential hazards or causes of the problems in a simple and orderly way. It provides you with the main roots of causes. It helps you simplify the complicated the problem, by taking them into parts that would be easy to follow and understand. The Fishbone diagram is helpful to be aware of the relationship between the issue and the possible factors in connection to it. The fishbone is the represented of the influence of every cause. [109] [124]

## 18.2 Head of the fishbone & Factors

The issue you are analyzing should be the head of your fishbone. This head is your target when you are making the cause and effect diagram. [109] [124]

How to create the Fishbone Diagram [109] [124]:

- Firstly, you have to start with the head, which represents the issue to be studied
- Start creating the backbone of your fishbone, which “Should be a straight line that is connected to the head “
- Try to find at least four causes or potential problems that could be a source of hazard or risk. Connect these causes with arrows as it will create the first bones of your fish.
- Now, it is the turn of brainstorming around each cause to find what could contribute to the problem. Use the 5 WHY METHOD or any process that could help you find more points such as the 4P’s (Policies, Procedures, People and Plant) to be focused more in the conversation.

Below is an example of how Fishbone looks [109] [124]:

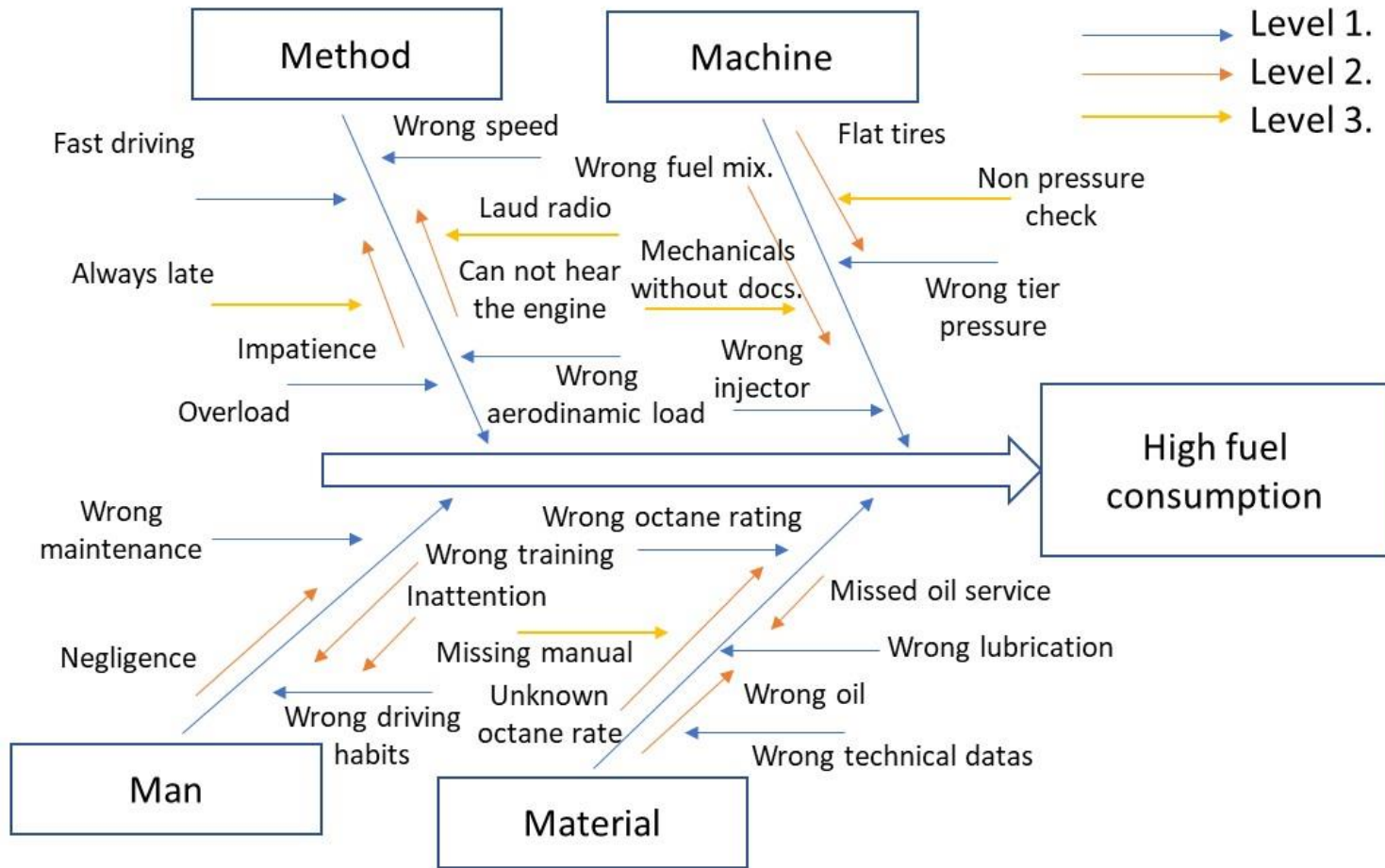


Figure 22.: Fishbone example

## 19. 5 Whys

The 5 Whys is a widely used root cause analysis tool. It is very easy to use and understand for the whole organization. The goal of this method is to find the real root cause of the problem with a simple question: "Why?". You just have to repeat it until you find the answer, i.e. the root cause. Each answer makes the base for the next question. But why do we call it 5 Whys? The rule is the following: in the most cases it is enough for you to ask Why only five times. These five times are enough to find the root of your problem. But sometimes you have to ask more than five and in some cases fewer questions may be enough. [109] [126]

The 5 Whys method originates from Japan. The developer was Sakichi Toyoda, who started to use the method in the Toyota Motor Corporation. We can find similar techniques in other companies too, but under another name. Ricarde Semlet at Semco practices uses three whys, this method has a similar goal like the 5 Whys. [109] [126]

The method is very flexible, it has not got strict rules about the questions and how long to continue to ask the questions until you find the root of the problem. If you use the method, sometimes you cannot get the correct answer for your questions. The quality answers always depend on you and your teams knowledge, experience and routine. [109] [126]

The 5 Whys is the basic tool of problem solving. A lot of team leaders, engineers and machine operators get a training about it in their first workdays. The new employees can see the processes and the production with a „fresh view“. It is very valuable for the company. The new employees can find the problems easier than the operators who worked there for a long time. [109] [126]

The 5Why technique nowadays is widely used in different types of factories. This technique walks hand in hand with the continuous improvement, kaizen, Six Sigma and with the lean manufacturing principles. [109] [126]

The following paragraph describes a very easy problem [109] [126]:

The vehicle will not start. (the problem)

- Why? – The tank is empty (First why)
- Why? – I forgot to go to the fuel station (Second why)
- Why? – Because I had to make a lot of homework (Third why)
- Why? – Because my professor gave a lot of homework (Fourth why)

- Why? – Because my grades are bad (Fifth why, a root cause)

The scrutinizing of this case could be taken further to a sixth, seventh, or further, however five cycles of inquiring as to why is usually adequate to get to the main driver. The key is to urge the inconvenience shooter to dodge presumptions and rationale traps and rather follow the chain of causality in coordinate additions from the impact through any layers of reflection to an underlying driver that still has some association with the first issue. Note that, in this illustration, the fifth why recommends a broken procedure or an alterable conduct, which is demonstrative of achieving the root cause level. [109] [126]

It is fascinating to take note of that the last answer focuses to a procedure. This is a standout amongst the most vital angles in the 5 Why approach - the genuine underlying driver should point toward a procedure that is not functioning admirably or does not exist. Untrained facilitators will regularly watch that answers appear to point towards established answers, for example, insufficient time, insufficient ventures, or insufficient labor. These answers might be valid, yet they are out of our control. Along these lines, rather than asking the inquiry for what good reason? Inquire as to why did the procedure fizzle? [109] [126]

The most important rule what you have to keep in mind in any 5 Why exercise is "people do not fail, processes do". [109] [126]

Try to use the following point during your work [109] [126]:

- Make 5 Whys with the management or the leaders
- Always build a team during the problem solving
- Use whiteboard during your analysis
- Always write down the problem and make sure that all people understand it
- Find the cause and effect relationship between the ideas, processes and problems
- Find the real root cause! This point can generate a lot of misunderstanding if your team make a wrong work during the root cause analysis
- Try to give precise answers
- Base your statements on facts and knowledge
- Tell your opinion and ideas about the processes not about the people
- Make a friendly atmosphere during the work

The 5 Whys is such a powerful root cause analysis tool that you can use in your company. But in the early years it got a lot of critics from Teruyuki Minoura, who was a managing director of global purchasing at the Toyota Motor Company. He said that it is a very basic tool to give a good solution to find the real root cause of the problems. [109] [126]

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## 20.Failure Mode and Effect Analysis - FMEA

### 20.1 Background

Failure Mode and Effect Analysis (FMEA) is a part of risk management techniques, developed for nuclear defense industries in the 1940's. It was formally used and developed by NASA to fail – proof Apollo missions, and improve reliability of space program hardware in the early 60's. The next adopter was the US military and specifically by the US Navy that implemented the MIL-STD-1629 in the early 70's. In late 70's, the FDA applied the hazard analysis. During the same period, it was the automotive industry which was guided by the liability costs to implement the FMEA and as a result, it recognized the advantage of this method to reduce risks linked to poor quality. In late 80's Ford issued a new document for suppliers. At the same time gas and petroleum industries started dealing with this methodology. In the mid 90's ISO and FDA issued design recommendation on this technique, and finally it was adopted by Seagate in 1996, which initiated application in design centers and process application. [127] [128]

### 20.2 Overview

Failure modes and effects analysis in general is a structured and an orderly proactive method for evaluating detailed process/systems information. [127] [128]

Major classification: The FMEA is subdivided into two major types as follows [127] [128]:

- DFMEA<sup>9</sup>: this method is mainly focusing on design – related problems, for example: used in newly designed product before reaching the final stage
- PFMEA<sup>10</sup>: this method is mainly focusing on process – related problems, for example: used on new or existing manufacturing and assembly lines

Sub – classification [127] [128]:

- Equipment FMEA
- Maintenance FMEA
- Service FMEA
- System FMEA

<sup>9</sup> Design Failure Mode and Effect Analysis

<sup>10</sup> Process Failure Mode and Effect Analysis

- Process FMEA
- Product FMEA

FMEA can be used in (Figure 23.) [127] [128]:

Existing systems or processes

New systems and processes

Existing systems/processes used in a new environment

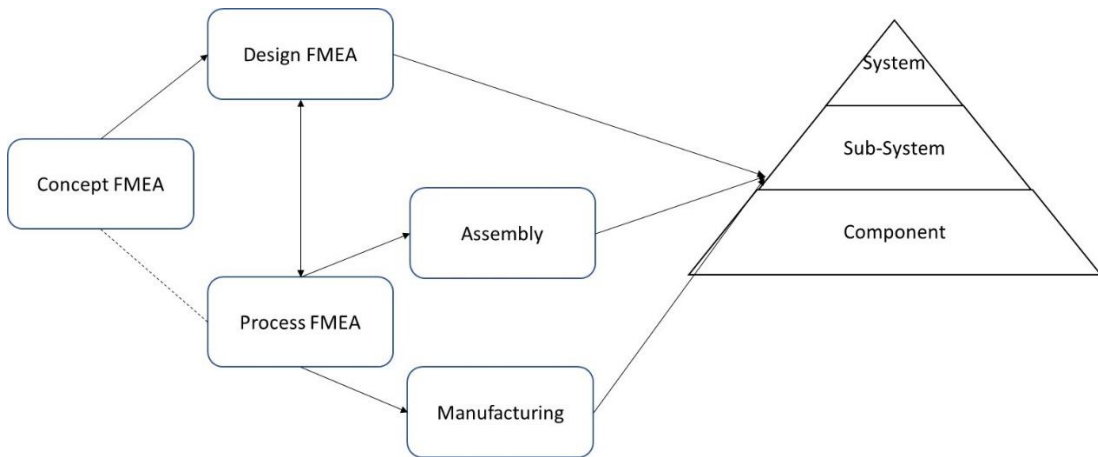
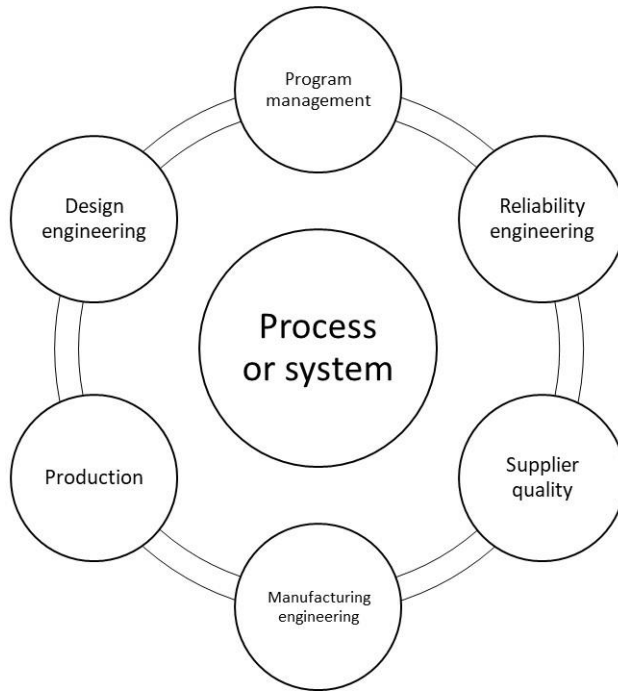


Figure 23.: FMEA method diagram [127]

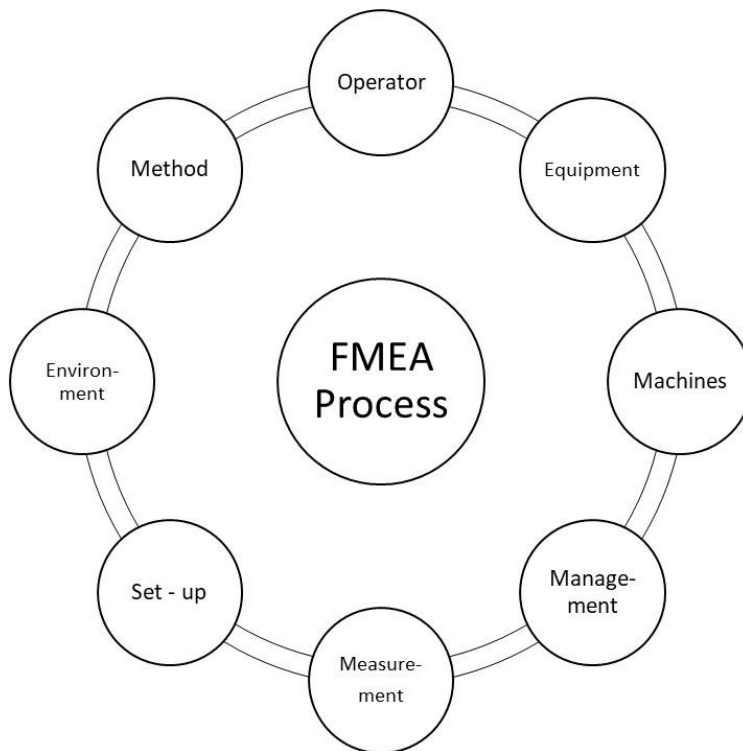
For new processes; it identifies potential bottlenecks, installation failure, or unintended consequences prior to realization. For existing processes, FMEA is mainly used to identify potential problems, or failures, the location of the failure (where), the method of the failure (how), and estimate the relative impact and other consequences. The results will be effectively used to precisely define the parts of this process that are most in need to change. FMEA in general requires teamwork, to create tabulated data and parameters of this specific process. The FMEA PIP template is the final step in this method; it consists of every detailed part in this process. The results will be bunch of percentages for every part of the process; these valuable percentages will clarify the failure probability of each component, determine the level of risk behind each part if failed, and the associated consequences for each part if failed. The FMEA provides a total evaluation and prevention of a specific process, which aids the team to correct this process proactively rather than reacting to opposite and undesirable events, emphasizing on the prevention in order to reduce possible harmful failures. A successful FMEA analysis starts with the understanding of functions

and performances of the system or process, thus; it requires data gathering from several and different sources [127] [128]:



*Figure 24.: FMEA data gathering diagram [127]*

FMEA technique considers process variability due to:



*Figure 25.: FMEA process variabilities [127]*

FMEA PIP template procedure [127] [128]:

In order to construct an effective FMEA template, a team should successfully complete orderly steps as follows [127] [128]:

Identify all components of the process: the team should know and locate all components that belong to a specific system or process, such as gas burner, compressor, steam cylinder, etc. In this first step, a drawing or map might be used for a clearer picture of the system/process. [127] [128]

Determine the function of each component: team should understand what the main purpose and working principle of every component along with the main function. [127] [128]

Determine the Failure mode of each component: after understanding the concept of each component. Specific and generic knowledge, history and experience will be used in this step-in order to realize and point to the failure modes with a high occurrence probability. The way in which every component will fail to perform is its intended function. Failure modes may be a result of upstream operations or a cause of failure of downstream operations. [127] [128]

Determine the effects of each failure mode for every component: when following a step by step functioning of a specific system/process, team members have to imagine the consequences behind a failure of that specific component, while exploring the severity of its effects in the production, quality, finance or other processes, and the customer's requirements. The team will apply this method for every associated component. The relationship between a single failure mode and its effect is not always 1 to 1. In certain situations, 1 failure mode can cause 2 or more effects on the process or system, and vice versa. A severity chart shall be used with a severity scale from 1-10. [127] [128]

In order to determine the reason behind each failure for every component: the main cause of each failure modes shall be explored; the team needs to investigate on each component in order to know the roots of these failures. This method might be applied in case of new severe failures or by unexperienced engineers. Very important to use the knowledge and the experience of the engineers and check the historical background of each machine parts. An occurrence ranking table can be used for easily determining the frequency at which a given cause occurs and leads to a failure mode. [127] [128]

Identification of each failure: in this case, team will determine the faults done by the employees when working in that process, such as poor maintenance, weak condition monitoring, bad quality equipment, and other similar industrial monitoring systems. [127] [128]

Define the values that represent the risk level of each failure mode including the O/I/R (Occurrence, Importance, and Risk): the selected team will introduce values in each failure mode for each component. The values are representing specific parameters that are [127] [128]:

- Occurrence value (O): determining the required value using tabulated values occurrence ranking, in order to specify the eventuality of potential causes that lead to failure modes.
- The importance (I): determine and evaluate the importance of each failure mode based on its severity and consequences, the failures with extreme severity level shall be put first and considered as the most important failures to be solved first, then other lower severity failures will be followed up.
- The risk (R): determine the risk value of each failure mode; it represents the risk level of this failure and what will happen to the process, system, or related components if this failure occurs. Generally; industries always designate the priority for failures with high risks.

Calculate the risk factor [127] [128]:

$$RF = I \times O \times R \quad (27)$$

After the team selected all values for each parameter; the risk factor must be calculated by multiplying the occurrence, importance, and risk together to get a final value. The resultant values will present the general severity of each failure mode for each component; these values will illustrate the most critical component within a process or system, which needs more focusing for purpose of specific improvements related to this component, in order to prevent future failure modes from occurring. [127] [128]

Report the recommended actions for each failure mode in each component:

The final step is to collect all information from FMEA template and report them, for purpose of making decisions concerning the failure modes with higher severity and its root component. The recommended actions shall be explored and stated for solving this problem and prevent it from occurring in future. [127] [128]

## 21. Pareto chart

### 21.1 Background

Pareto chart, also called; Pareto bar graph, Pareto analysis, or Pareto diagram, postulated in the 19th century by Vilfredo Federico Damaso Pareto who was an Italian engineer, sociologist, economist, political scientist, and philosopher. Pareto professed that a large percentage of fortune is possessed by a relatively small percentage of the population. Pareto reached its principle, which says that 80% of the problem is considered for by 20% of the factors; in other words; 80% of the trouble comes from 20% of the problems. Consequently; it makes sense to concentrate on the “vital few” rather than the “trivial many”. [127] [128]

### 21.2 Overview

Pareto principles are clarified into bars graph; the length of each bar is representing the frequency and severity of the associated problem/failure. The bars are arranged in a gradation method from highest to lowest failure severity; the highest the failure severity is, the longest the bar length is. The problems are generated and collected using various problems solving techniques, such as the FMEA. Problems of every component are listed within the FMEA template, and then placed with the Pareto chart represented as bars. [127] [128]

The benefits of Pareto charts [127] [128]:

- Analyzing the severity of problems and causes in a process
- Focusing on the most critical problem or cause within a list of various problems
- Breaks a huge problem into smaller pieces
- letting the team analyze wide causes by looking at specific components
- It also allows for communication using data as length of bars

### 21.3 Pareto bar graph procedure

In order to complete a successful and ensure effectiveness of a Pareto bar graph, team members have to follow sequenced steps to accomplish the highly recommended procedure which is listed as follows [127] [128]:

- Recording the collected data: list of components and each associated data
- Put the data in order depending on the degree of severity problems on a sheet

- Labeling the left-hand vertical axis of the graph with the risk factor values generated in the FMEA template
- Labeling the horizontal axis of the graph with the components from left to right, highest severity to lowest, in order to construct bars
- Labeling the right-hand vertical axis of the graph with percentage values from 0 – 100%
- Plot a bar for each component from left to right, from highest to lowest values of risk factor
- Construct the whole bar graph, and explain it.

The following chapter contains an example about 5S audit, two TPM plans and FMEA. [127] [128]

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## 22. Case Studies – 5S Audit

Table 7.: 5S audit sheet example

Auditor:		Area Scanned:			Date:	
Areas	5S Evaluation and Scoring Criteria				Score 0 - 5	Notes, problems
	0 = 7+ problems	2 = 5 problems	4 = 3 problem			
	1 = 6 problems	3 = 4 problems	5 = 2 problems			
Office area	Processes are clear, no personal documents and tools, the tables and corridors are clear, there is no unnecessary equipment				2	Unnecessary documents found on the Table 3.
Documentations	The shelves and folders are clear, it has signs, the documentation processes follow the company 5S rules				3	
Measuring room, Laboratories	The equipments are clear, the vinyls and signs are in a good condition, the measuring equipments are valid				1	The vinyls are in a bad condition
Tools, equipment and measuring gauges	The equipments are clear, the vinyls and signs are in a good condition, the equipments have defined places like shadow table				5	
Cleaning Equipment & Materials	The equipments are clear, the vinyls and signs are in a good condition, the equipments have defined places like shadow table				5	
Emergency Equipment and Boxes	The equipments are clear, the vinyls and signs are in a good condition, the emergency equipments are valid, there is not any barrier in the emergency corridors				5	
Maintenance Equipment	The equipments are clear, the vinyls and signs are in a good condition, the equipments have defined places like shadow table				5	
Visual Management System	The Visual Management System is up to date, the employees know the numbers				4	KPI numbers are visible, the trend show positive
5S, KPI Numbers and Actions	The previous 5S actions are done, the employees know the 5S actions				5	
<b>Total</b>					<b>35</b>	<b>/ 9 = 3.8</b>

## 23. Case Studies – TPM I.

The TPM I. case study describes a plastic injection machine TPM plan design. [110]

- Inspection of the machine: Inspect mishandled material, improper housekeeping and possible leakage. [110]
- Evaluation of Data received: The Data includes the machines history of shutdowns, maintenance, malfunction dating [110]
- Design the total production maintenance plan: The designed plan includes all data collected and inspection conducted to generate a plan for the company. [110]

### 23.1 Inspection of the machine

Inspection took place in three timings, early shift, mid shift and late shift. The inspection included overall performance, maintenance and what 5S strategy the company was using. [110]



*Figure 26.: Slip metal pathway [110]*

Figure 26. shows a neglected metal runway that eventually became hazards due to its slippery touch. Neglecting proper housekeeping of this issue will turn into fatal injuries for the workers. [110]



*Figure 27.: improper housekeeping [110]*

This Figure 27. shows material not being placed within the boundaries designated for them. Improper housekeeping of material will take up necessary spaces that technicians would use to maintain the machine and could present a challenge for them to perform their work if being restricted in their movement. [110]



*Figure 28.: Machines occupying inappropriate spaces [110]*

In addition to materials being properly organized and placed within their designated boundaries, machines also have to be placed in such boundaries. Figure 28. shows machines being placed around the machine and not returned to their spaces after use. The machines are occupying space needed for the technicians to perform their tasks and should be placed back to their own area. [110]



*Figure 29.: Improper housekeeping #2 of barrels [110]*

The figure shows a barrel filled with plastic material to be sucked through the tubes and into the machine to produce plastic products. Barrels should be placed on top of wooden platform and hoses are not to be kept so close to the ground. [110]



*Figures 30.: Improper housekeeping #3 of Barrels-Material [110]*

Figure 30. shows barrels not being placed on their designated boundaries, the figure shows a group of barrels on a wooden platform placed beyond their boundaries, and a barrel tipped off to the side with a chance of falling and scattering all the plastic material preserved inside. [110]



*Figure 31.: Disordered Material [110]*

Figure 31. shows scattered storage containers and material and boxes being improperly placed alongside the red boundary lines, which are purposely marked to their place these containers in them. [110]



*Figure 32.: Disordered Material [110]*

Figure 32. shows a barrel being misplaced and not well taken care of - the barrel is tilted while a recycling hose is dipped inside to send the recycled material into it. This could lead to the barrel falling, causing the material to scatter on the floor. [110]



*Figure 33.: Improper maintenance of pipes and valves [110]*

Figure 33. shows the pipeline system of the machine being neglected and mistreated. Dust and other material have accumulated on the pipeline, valves and filters. This is an important section of the machine and should be treated properly and cleaned daily. The continuous accumulation of dust and particles could block the valves from opening or closing. [110]



*Figure 34.: Improper housekeeping of machine [110]*

The figure shows plastic material accumulating on the machine from a dislocated hose scattering the plastic material on the machine. The machine should be properly cleaned and plastic material to be gathered for recycling.



*Figure 35.: Misplaced Cables and Wires [110]*

Figure 35. displays cables being misplaced on the pathway leading to the electrical panel of the machine. All cables, wires and other material should be placed in a proper area to avoid any hazards that could result from its being misplaced. Technicians could accidentally tangle with the cables, which causes injuries. [110]



*Figure 36.: Oil leakage [110]*

Figure 36. shows an oil leakage from the machine resulting from a damaged pipe. This is quite dangerous if not properly maintained as an oil spill could cause fire eruptions and technicians could possibly slip and fall if not paying attention, which causes injuries. It could also deprive the machine from its oil needs, as a result of which it won't work efficiently. [110]



*Figure 37.: Improperly maintained pipe [110]*

This figure shows improper maintenance performed on the pipe of a recycled shredding plastic machine. The pipe is a little tilted and duct taped in order to be held together. If not properly maintained, the pipe could break from continuous use, damaging the machine all together. Proper maintenance would be to weld the pipe or to purchase a new one. [110]

## 23.2 Evaluation of the data received

The total production plan designed for the machine is based on data which the company has disclosed and entrusted. The data was summarized from the machines log history and it contains a variety of failures throughout the machines working period dating back to 2010. The data includes failures in 4 sections [110]:

- Electrical: The assigned technicians are required to inspect electrical wires of the machine, inspect the system power, absorption efficiency, unit sensors, and overall controls of the machine. This is considered as a priority; the maintenance of electrical systems prevents catastrophic damage to the machine that could be hazards to the employees and damage the machine beyond repair. [110]
- Hydraulic: The assigned technicians are required to inspect the pumping system of the machine, valves, motors, cylinders, overall flow of the machine. The purpose is to remove contaminates that restrict the process flow from the system and prevent future failures that might occur. [110]
- Mechanical: The assigned technicians are required to inspect various parts of the machine such as injection tools, valves, bearings, tubes, castings, and overall mechanical parts of the machine. Maintaining and inspecting the machine mechanically on a regular basis will prevent future hazards, damage to the machine and it will keep the efficiency of the machine at its highest. [110]

- Pneumatic: The assigned technicians are required to inspect for any leakage that is or might be occurring in the machine, also to inspect the overall flow of the machine. It is important to daily check these failures. The blockage of flow could lead to machine failure and decrease efficiency. [110]
- General: The assigned technicians are required to daily inspect the smallest issues that might occur, such as oil leakage, cleanliness of the machine, oil tank, loose parts, screws, bolts. Maintaining these small issues can prevent failure to the machine and prevent accidents. [110]

Each point of data included the following information [110]:

- Date when the failure was presented.
- The time spent with maintenance on the machine.
- The issue and failure section the machine went through.
- The method and tools used to solve and fix this failure.

### 23.3 Design the total production maintenance plan

TPM Maintenance Plan								
			Location:		Responsibility:			
No.	Field Type	Criterion	Methods to perform	Tools	Time (Hr)	Freq.		Check boxes/Signature
						Daily (Start of shift)	Weekly (start of weekly shift)	

Figure 38.: Screen shot of total production maintenance plan [110]

Figure 38. describes the design form of the total production plan intended - it shows [110]:

- No: The number of areas that need inspection/repair/modification.
- Field type: The area in which the failure might occur (Electrical, Mechanical, Hydraulic, and Pneumatic)
- Criterion: The possible failure.
- Methods to perform: The solution used to prevent the failure.
- Tools: All equipment that the technicians used to fix the failure.
- Time: time taken for the technicians to finish the task.
- Frequency: The number of occurrences suggested to perform the solutions.

1	Electrical	Absorption failure	Inspect/improve absorption status		1	✓
2	Electrical	Heating Controls defaults	Inspect/improve heating control status		1	✓
3	Electrical	System Controls defaults	Inspect overall controls of machine		2	✓
4	Electrical	unit sensors and cables failure	Inspect/supply unit sensors and cables	Inductive sensors, cables,	3	✓

Figure 39.: Screen shot of total production maintenance [110]

Figure 39. describes the failures that might occur in the electrical field - it shows four major failures that the machine encountered frequently. The failures are [110]:

- Absorption failure: Failure to absorb the plastic mold. Maintenance is done on a weekly basis
- Heating control defaults: Failure in oven heating to heat the mold.
- System control defaults: Overall failure in the machines system controls.
- Unit sensors and cables failure: damaged sensors and cable which lead to failure.

Maintenance on Electrical failure should be performed on a weekly basis and preferably at the beginning of the week (Monday) to make sure all functions are running smoothly with continuous inspection. [110]

5	Hydraulic	Gripper failure	Inspect gripper and repair/replace		3	✓
6	Hydraulic	Drilling tool failure	Inspect drilling tool and repair/replace		3	✓
7	Hydraulic	Cylinder failure	Inspect Cylinders and repair/replace		5	✓

Figure 40.: Screen shot of total production maintenance plan [110]

Figure 40. describes the failures that might occur in the hydraulic section of the machine, the failures are [110]:

- Gripper fault: Possible damage of Gripper.
- Drilling tool failure: drilling tool not responsive to orders.
- Cylinder failure: Damage to cylinders.

Maintenance on hydraulic failure should be performed on a weekly basis to ensure all functions are running normally and with no interceptions. [110]

8	Mechanical	Blower, cutting edge damage	Inspect Blower, cutting edge and repair/replace		2		✓	
9	Mechanical	Blower, pin tools damage	Inspect Blower, pin tools and repair/replace	Blower plug socket	1		✓	
10	Mechanical	Blower holder fracture	Inspect Blower holder and repair/replace	pipe tools 135-6s.t	2		✓	
11	Mechanical	Blower failure	Inspect Blower and repair/replace		5		✓	
12	Mechanical	Clamping unit failure	Inspect clamping unit and repair/replace		1	✓		
13	Mechanical	General Machine Maintenance	Inspection and cleaning of machine		6		✓	
14	Mechanical	Screw release	Release screw and inspect for damages		1	✓		
15	Mechanical	Injection tool change	Change injection tool and inspect for damages		5		✓	
16	Mechanical	Closing unit failure	Inspect Closing unit and repair/replace	pipe tools 120-as poli	3		✓	
17	Mechanical	Air blow out from tube blower	Inspect tube blower	Pipe tools Polishing	1	✓		
18	Mechanical	blower pin closing edge failure	Inspect blower pin		1	✓		
19	Mechanical	Facious wrench fracture	Inspect Facious wrench and repair/replace	12-inch round steel	1		✓	
20	Mechanical	Bearing fracture	Inspect Bearings and repair/replace	Bearing	2	✓		
21	Mechanical	Protective fences damage	Inspect Protective fences and repair/replace	Polycarbonate plate	1	✓		
22	Mechanical	30 Liter cooling drum fracture	Inspect 30 Liter cooling drum and repair/replace	Cooling Sleeve lathe	2	✓		
23	Mechanical	Blower unit failure	Inspect Blower unit and repair/replace	M16 / M12 bushings	1	✓		
24	Mechanical	Blow- pin failure	Inspect Blow- pin and repair/replace		1	✓		
25	Mechanical	Machine tool polishing	Polishing tools before replacement	pipe tools 160-as	2	✓		

Figure 41.: Screen shot of total production maintenance plan [110]

Figure 41. describes the various mechanical issues that the machine has/had frequently, the failure of not maintaining the machine mechanically. The issues described will not only damage the machine in the long term but will also decrease its efficiency and adversely affect product quality. The main failures are [110]:

- Blower failure: Most common causes of blower failure is the continuous build-up of dirt. Failure to maintain the blower will eventually damage the blower causing extra cost of replacing it, since repairing will not usually bring back its efficiency.
- Injection tool damage: The purpose of the machine is to produce plastic products. This is done by injection molding, which requires an injection molding tool. They are quite expensive and the failure to maintain them on a regular basis will add cost on the company if they need replacing. Damaged injection tools will decrease the quality of the product.
- Bearing fracture: negligence of maintenance on bearings will cause them to overload and cause them to fracture and eventually break. Fatal accident might occur if the damage occurs while the machine is still operating.

Maintenance on Mechanical failures should be performed on both daily basis (Early shift) and at the beginning of the week (Monday) with continuous inspection to make sure all mechanical functions are in god condition. [110]

26	Pneumatic	Air Shortage	Check air leakage	1'com.	1	✓		
27	Pneumatic	Filter overload	Change filter		1	✓		

Figure 42.: Screen shot of total production maintenance plan [110]

Figure 42. describes the pneumatic failures that might occur on the machine on a daily basis. It focuses on leakages, mainly air leakages that occur from hose ruptures, damaged valves or damaged blower units. Maintenance should be performed on a daily basis to ensure no air leakage

is occurring. Air leaks cause a decrease in the machines efficiency and forces the machine to use more power to perform which could cause machine overload and overheat. [110]

28	General	Oil leakage	Check pipes hoses oil tank ...	Seal	1	✓	
29	General	Oil level is low	Oil level Check and fill up		1	✓	
30	General	Housekeeping	Perform the 5S strategy		1	✓	

Figure 43.: Screen shot of total production maintenance plan [110]

Figure 43. describes the general maintenance that should be done on the machine on a daily basis (Early shift). The maintenance generally focuses on oil leaks, oil change, oil fill-up, cleaning the machine and polishing. [110]

Every point was analyzed and evaluated, and a summary was produced from these points to form a total production maintenance plan. This plan will help the company to manage these failures in the future. In theory it will save maintenance costs, by decreasing the downtime on the machine and the time wasted performing maintenance. These factors lead to reduction of the total budget costs of the machine itself. [110]

Details the total production maintenance plan developed are pointing to the areas of specialty, their point of interest are methods able to solve the failures and associated tools needed to complete the task. [110]

## TPM Maintenance Plan

Machine ID:						Responsibility:			
No.	Field Type	Criterion	Methods to perform	Tools	Time (Hr)	Freq.		Check box/Signature	
						Daily (Start of shift)	Weekly (start of weekly shift)		
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									

*Figure 44.: TPM plan example I. [110]*

## 24. Case Studies – TPM II.

The Figure 45. describes a headline of another TPM plan about a screw compressor. [109]

Total Productive Maintenance & Cleaning Plan					
Machine name:		Location:	Person in charge:		
Nr.	Machine parts/processes	Problem	Activity	Interval	Date & Signature

Figure 45.: Screenshot of Total Productive Maintenance Design [109]

This screenshot design of the TPM plan is focused to indicate certain points such as [109]:

- The machine name as indicated.
- The location of this machine at a compressor house.
- The person in charge to follow up with the plan is the maintenance leader.
- Certain numbers of these machine parts that are considered as the most critical parts at this rotary screw compressor that could be in the direct effect positively or negatively towards this machine efficiency.
- The potential problem of each part.
- The proposed activity or solution to avoid this problem as a part of preventive maintenance.
- The intervals that set a certain regular time to follow up and check out the efficiency of those parts or change them if needed from time to time to ensure the high efficiency of the machine.

Nr.	Machine parts/processes	Problem	Activity	Interval	Date & Signature
1.	The V-belts	Not transmitting power	Check Re-tension the V-belts	weekly	
2.	Mat Filter	Clogging	Check ,Clean orRenew	weekly	
3.	Air Filter	Clogging	Clean ,Change	weekly	
4.	Electric Motor	Efficiency	Check Compressor Motor	3 MONTH	
5.	Pressure Relief Valve	Excessive pressure	Check PLV	6 MONTH	
6.	Oil Cooler and Air Cooler	Clogging cause high temperatures	Check for clogging	monthly	
7.	Oil Level	Increase it temperature	Check,Top up the oil to the max	weekly	
8.	Oil Change(Oil Separator&Cooler)	Contamination	Change	8 month	
9.	Oil Filter	Clogging	Change	weekly	
10.	Changing the Oil Separator Cartridge	Efficiency	Change	8 month	
11.	Fitting components	Oil Leakage	Check the fittings comp.	monthly	

Figure 46.: Screenshot of Total Productive Maintenance [109]


This Total productive maintenance design describes gathering the most critical parts that would effect the work of this compressor – it is indicated in the following [109]:

- V-Belt: It has a potential problem in not transmitting the necessary power to the compressor due to a limited range by the pressure spring of the belt tensioning. So, the

solution is either to replace it with a new V-belt if needed or re-tension the V-belts if they have stretched - we have to check it weekly. [109]

- Mat filter: clogging possibly could occur, and the solution proposed is to renew if necessary or rinse the mat in water of approximately 40.C. If necessary, use a mild washing powder. The mat can also be tapped, vacuum cleaned or blown out with compressed air. Rinse out oily dust using warm water with a mild solvent added - and we have to check it weekly. [109]
- Air filter: clogging possibly could occur. The solution proposed is to renew or clean the air filter cartridge by tapping, Tap the air filter cartridge several times on the front with the ball of the hand or cleaning the air filter cartridge with compressed air. Blow dry compressed air at a pressure of not more than 5 bars at a slant from the inside to the outside of the air filter cartridge surfaces - we have to check this weekly. [109]
- Electrical motor: could be stopped or not working as efficient as it supposed to be. We should check the Compressor motor where the electrical motor bearings should be permanently greased - we check it every three months. [109]
- Pressure relief valve: it is really important to control and limit the excessive pressure in the compressor. Sometimes it gets problems in its spring and the Labe seat that could be replaced or highly checked. This valve does not normally fail on its own - we should check it every 6 months. [109]
- Oil Cooler and Air Cooler: heavy clogging may cause high temperatures in the oil circulation. The oil cooler and air cooler must be checked and cleaned for clogging regularly every month. Clean the soiled cooler with water or steam jet only in washing areas that are suitable for such cleaning work and provided with an oil separator. [109]
- Oil level: if there is no enough oil, it will cause a big damage to the compressor and increase it temperature. Check the oil level weekly through the oil level sight glass with the compressor shut down. If necessary, top up the oil to the maximum level. [109]
- Oil Change (Oil Separator and Oil Cooler): contamination is the cause of the problem. Check the oil regularly. The oil change interval is dependent on the degree of cooling air contamination and on the ambient temperature. The oil must be changed more often, if necessary: the interval should be halved but the proposed interval is 8 months. [109]
- Oil Filter: clogging could happen, so we should change the oil filter weekly.


- Oil Separator Cartridge: it has a potential to not working efficiently to separate the oil or to do the task as supposed to. Keeping the recommended maintenance intervals of the air and oil filters is the solution to keep it efficient. However, at certain points it needs to be changed due the service life of the oil separator cartridge. Which is strongly influenced by the degree of contamination - the proposed interval is 8 months. [109]
- Fitting components: it has the potential in leading to oil leakage. The leakage in the compressors is considered one of the most common problems. The pressure system in the compressors could affect the oil. The flow of the oil from jags of the fitting element is where we need to renew the fitting components in case needed. Or, screw the fitting more or talk to the manufacturer if needed - the proposed regular check is monthly. [109]

Nr.	5S Job	Schedule	Date & Signature	Critical areas
1.	Place indicators	weekly		
2.	Item indicators	weekly		
3.	Amount indicators	weekly		
4.	Sweep around line	weekly		
5.	Sweep within line	weekly		
6.	Sweep areas and walkways	daily		
7.	Unneeded equipment, tools, furniture	every 2 weeks		
8.	Necessary information is not visible	daily		
9.	Other cleanin problems of any kind exist	weekly		
	Signature of the Facility Manager	Signature of the TPM designer		

*Figure 47.: Screenshot of Total Productive Maintenance [109]*

The TPM plan also indicated the 5S job where (Place indicator, item indicator, amount indicators sweep around line and sweep within line) scheduled weekly. Unneeded equipment tools, furniture should be checked every 2 weeks. Finally, the sweep areas and walkways should be checked daily. There is also a part called Critical Area, where the real picture of internal parts of this screw compressor are shown. In the end, there is a signature space for both the TPM Designer and the Facility Manager to accept the accomplished work that followed this plan. [109]

## Total Productive Maintenance & Cleaning Plan

	Machine name:	Location:	Person in charge:		
Nr.	Machine parts/processes	Problem	Activity	Parameters	Interval
1.					
2.					
3.					
5.					
6.					
Nr.	5S Job	Schedule	Critical areas		
1.					
2.					
3.					
4.					
8.					
9.					
	Signature of the Facility Manager	Signature of the TPM designer			

*Figure 48.: TPM plan example II. [109]*

## 25. Case Studies – FMEA

Table 8.: Small part of a FMEA example [127]

RTU process	Function	Failure possibility	Effect of failure	Reason of the failure	Identification of failure	I	O	R	RF	Recommendation
<b>Steam cylinder</b>	Steam production	Scales accumulation In the cylinder and on the electrodes surfaces	Steam production decrease, humidity control lost	Steam cylinder quality and softened water quality	Condition monitoring	9	10	9	<b>810</b>	Steam cylinder replacement
<b>Compressor</b>	Refrigeration system	Wear, tear, age, overheating mechanical damage of the internal component such as windings	Mechanical damage of the internal component such as windings, no air conditioning supply	Poor maintenance, excess amount of refrigerant	Condition monitoring	9	3	6	<b>162</b>	Periodic, good preventive maintenance
<b>Fan blower</b>	Forces the air blown into ducts	Scales accumulation, and age causing bearing run-out Teared timing belt	Decrease or stoppage in the amount of supplied air	Poor cleaning of the fan, poor air filtration, poor maintenance	Condition monitoring	6	2	3	<b>36</b>	Seasonal cleaning of the fan blower wings and preventive maintenance for mechanical parts, periodical replacement of timing belt
<b>Electrical motor</b>	Drive the fan blower	Wear, age, bearing run-out	Stoppage of air fan blower and air blow to the space	Poor maintenance	Condition monitoring	10	3	3	<b>90</b>	Good preventive maintenance
<b>Gas burner</b>	Heat generation to warm the air, provides heat during winter	Spark plugs, ignition	Heat control lost, no fire ignition	Poor maintenance	Condition monitoring	10	4	3	<b>120</b>	Preventive maintenance, scheduled spark plug replacement
<b>Air filters</b>	Filtrates the coming air, cleaning from dirt	Dirt, scales accumulation	Dirty air inside the RTU, contaminate other mechanical components lead to failures	Poor maintenance	Condition monitoring	10	4	5	<b>200</b>	Scheduled replacement of the filters, preventive maintenance
<b>Humidifier</b>	Humidify passing air, adding moisture	Water nozzle blockage, scaling, water leakage, and build up deposits	Overheating, cracking components, humidity control lost	Poor maintenance	Condition monitoring	10	3	3	<b>90</b>	Seasonal cleaning of the humidifier and components replace if need

<b>RTU process</b>	<b>Function</b>	<b>Failure possibility</b>	<b>Effect of failure</b>	<b>Reason of the failure</b>	<b>Identification of failure</b>	<b>I</b>	<b>O</b>	<b>R</b>	<b>RF</b>	<b>Recommendation</b>
<b>Water softener cylinder</b>	Decrease the water hardness	Blockage, leaking, damage of the water pipelines or valves useless bed resin	Insufficient softening of water, hardness still present softened water control lost, decreased supply of softened water faster ruining of steam cylinder/scale	Poor preventive maintenance improper bed resin cleaning or changing the absences of sodium ion in the resin pellets	Condition monitoring	1	3	5	150	Seasonal-maintenance, clean the water pipelines, bed resin, provide proper drainage, add resin if needed
<b>Brine tank</b>	Contains salt, supply water softner with sodium	Salt bridging useless salt pellets expired, pipline blockage, not enough salt pellets quantity poor quality, purity of salt	Insufficient sodium supply, water not enough softener control scale accumulation in the steam cylinder	Poor maintenance, improper cleaning of the brine tank, required salt quantity, decreased sodium level	Condition monitoring	10	5	3	150	Seasonal-maintenance cleaning the brine tank, adding salt to required volume, changing salt with high purity salt
<b>Economizer</b>	Regulate the amount of entering air flow	Scales dirt accumulation on the blades sensors	Insufficient air volume entering the RTU, improper air feed to the space	Poor maintenance, cleaning of blades, electrical wiring of sensors	Condition monitoring	8	2	2	32	Seasonal cleaning of the metallic blades, and check of electrical wiring and sensors test for proper functioning
<b>Ductworks</b>	Tranport fresh and humidifier air to inside space	Scales dirt, contaminates accumulation inside ducts	Contaminated air flows to the space effect on humidity/moisture level, uncomfortable working conditioned	Poor cleaning of the internal duct space	Condition monitoring	7	2	2	28	Seasonal cleaning of internal opening of the ductworks

Pareto graph:

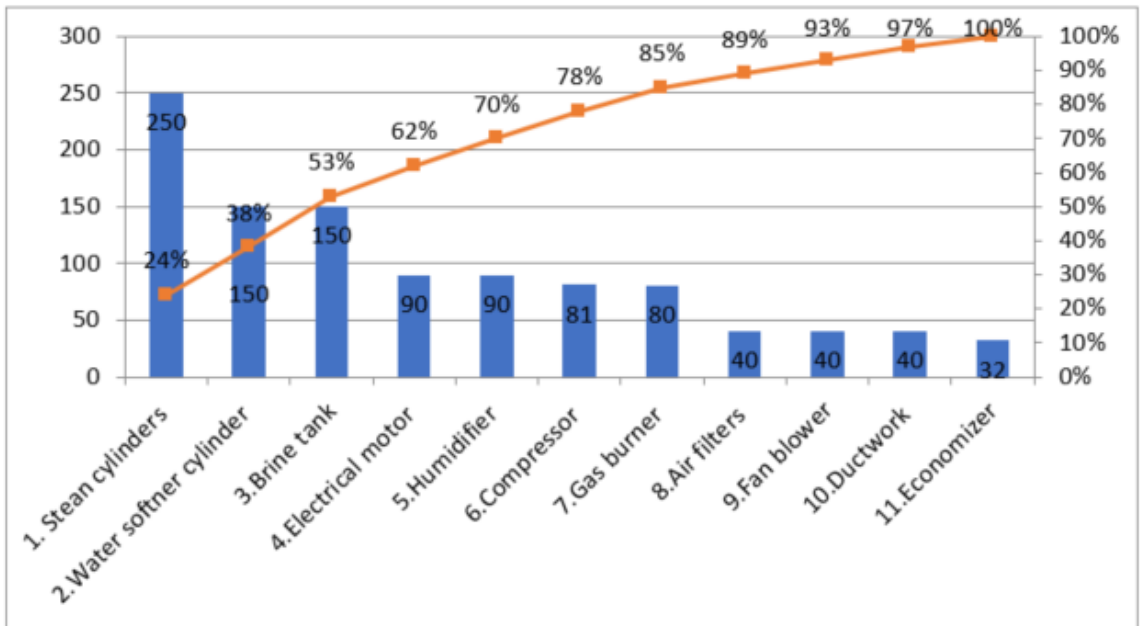


Figure 48.: Pareto chart [127]

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