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Based on Total Productive Maintenance and the key performance indicator Overall Equipment Effectiveness

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Univ.-Prof. Dr.-Ing. Dipl. Wirt.-Ing. Prof. eh. Dr. h.c. Wilfried Sihn
(E330 Institut für Managementwissenschaften, Bereich: Betriebstechnik und Systemplanung)

Univ.-Ass. Dipl.-Ing. Klaudia Kovacs
(E330 Institut für Managementwissenschaften, Bereich: Betriebstechnik und Systemplanung, Fraunhofer Austria Research GmbH)

eingereicht an der Technischen Universität Wien

Fakultät für Maschinenwesen und Betriebswissenschaften

von

Torben Baube

[redacted]

Wien, im Januar 2018

Torben Baube

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Kurzfassung

Neue Technologien, Datenverarbeitungssysteme und Industrie 4.0 machen Maschinen und Werkzeuge mehr und mehr Komplex. Während Unternehmen enge Zeitpläne haben, wird der Platz für Fehler immer geringer. Neue Anforderungen an Wartung und Wartungsaktivitäten werden relevant. Besonders für klein- und mittelständische Unternehmen ist es schwierig mit den Weltkonzernen mitzuhalten und konkurrenzfähig zu bleiben.

Der Konzeptaufbau basiert auf der Analyse bestehender Wartungskonzepte und -strategien sowie Methoden, welche den Prozess des Wartungsoutsourcings unterstützten. Das entwickelte Wartungsservicekonzept ist eine Kombination des aktuellen wissenschaftlichen Standards, Lean Maintenance und Total Productive Maintenance sowie des korrespondierenden Leistungsindikators – Totale Anlagenverfügbarkeit. Die Validierung des entwickelten Konzepts soll in einem Fallbeispiel mit reliabel Daten überprüft und auf Wirtschaftlichkeit hin überprüft werden. Das Ergebnis des Fallbeispiels zeigt, dass Outsourcing von Wartungsaktivitäten mit Hilfe des erstellen Wartungskonzept einen Wettbewerbsvorteil darstellt. Während in dem untersuchten Fall, outgesourcte Wartungsaktivitäten zu einer höheren Produktion und geringeren Kosten führten, sind Langzeiteffekte und andere Wartungsmöglichkeiten nicht in Betracht gezogen worden. Des Weiteren, ist der neueste wissenschaftliche Ansatz – Lean Smart Maintenance – nicht berücksichtigt worden, welcher Wartungsaktivitäten noch weiter verbessert. Dennoch zeigt das Konzept, wie viel Potential in der regelmäßigen Wartung und geplanten Wartungsarbeiten hat. Insbesondere für klein- und mittelständische Unternehmen.

Schlagwörter: Wartung, Total Productive Maintenance, Outsourcing von Warnung, Totale Anlagenverfügbarkeit, Wartungskonzept

Abstract

Through new technologies, data collecting systems and connection by the internet of things, equipment and machines are getting more and more complex. While companies have a tight time schedule, space for mistakes and breakdowns decreases. New demands in maintenance and maintenance activities also come into existence. Especially, for SMEs it is difficult to stay up to date and keep up with global players. The purpose of this paper is to analyse outsourcing of maintenance activities as one possibility for SMEs, to guarantee optimal equipment efficiency and performance.

By analysing maintenance approaches, strategies, concepts, maintenance key performance indicators and implementation, a framework for outsourcing maintenance activities is to be set up and applied in a case study. The framework of the service maintenance concept for SMEs is derived from the state of the art, lean maintenance and total productive maintenance and key performance indicator – overall equipment efficiency. Further, valid and reliable data from the case study provides the concept. Finally, a cost analysis helps to evaluate the financial benefit for the outsourcing company. This leads to the result, that SMEs which outsource maintenance activities, based on the developed concept gain a competitive advantage. Whilst, in the investigated case, outsourcing maintenance activities could lead to higher productivity and lower costs, long term effects and other maintenance possibilities were not considered as a possibility. Moreover, the latest approach to lean smart maintenance is not yet considered as an option which further improves maintenance activities. However, the concept and the case study showed how much potential constant maintenance and planned maintenance activities has, especially, for small and medium enterprises.

Keywords: maintenance, total productive maintenance, maintenance outsourcing, overall equipment effectiveness, maintenance concept

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1 Introduction

Nowadays, companies act in a fast-changing surroundings while dealing with changing needs and demands of customers. The pressure on companies grows even bigger the more internationally or globally they interact. The higher the equipment intensity and complexity, the more important is flexibility and agility in this context. For this, a company needs to rely on its equipment and machines, which are maintained by efficient equipment management.

To tackling these challenges, companies can choose from various competitive strategies, via innovation, process optimisation or to human resource management. One approach with which to gain a competitive advantage is that of equipment management. For this, it is necessary to gain an overview of possible losses and to analyse them before being able to optimise the process or the equipment itself. In particular, maintenance has a major impact on the equipment availability.

The analysis of the effectiveness of equipment and the improvement of its availability, performance and quality of equipment is complex. If companies take the decision to analyse this situation, they encounter many challenges. Challenges involve deciding who is analysing the equipment effectiveness, how to define it, how to measure it and most importantly, how to improve it. In Europe 99% of companies are SMEs and often do not have the knowledge, capacity and the resources to do these analyses. One option for SMEs could be to outsource the maintenance activities. The questions which arise are thus, how to evaluate, if SMEs have a proper maintenance concept and if they do not have one, how could a maintenance service concept look like if SMEs outsource this task to the manufacturer?

To answer these questions there must be an analysis of the state of the art of maintenance approaches that focuses on the different losses. The well-known concept TPM shall be considered as an opportunity. Further, different outsourcing scenarios, outsourcing service provider and the measurement system need to be taken into account as well. Based on the results a maintenance concept shall be developed that could be used to implement a maintenance service by an OEM based on the OEE. Furthermore, a gap analysis must be made to check possibilities to improve the OEE on feasibility, economic and environmental aspects by evaluating them. To improve the equipment availability regarding feasibility, economic and environmental aspects.

The concept shall be applied to a case study with SME customers of a manufacturing company of bakery equipment. The SMEs are being surveyed according to their maintenance behaviour. The validation of the overall equipment effectiveness is the fundament for the rating of the maintenance behaviour. If there is no available and reliable data yet, this data needs be collected first. Based on the OEE and the following indicators; performance, availability and quality, the temporal maintenance situation in the SMEs in this branch shall be evaluated. Furthermore, the temporal costs of the investigated SME shall be compared with the possible gross margin, if the SME were to outsource the maintenance activities. To derive and evaluate the possibilities of the developed service maintenance concept and the outsourcing of maintenance activities.

Future evaluation must be made of this concept to prove it and to analyse how effective and successful it is in the long-term and in other branches.

Depending on the evaluation, a maintenance concept for a service providing original equipment manufacturers shall be designed.

Hence, the research question is formulated as follows:

- **“How can a service provided maintenance concept for Small and medium-sized enterprises (SMEs), based on total productive maintenance (TPM) and the corresponding key performance indicator (KPI) overall equipment effectiveness (OEE) look like.”**

It is aimed to answer the following sub questions:

- **Q1:** How to set up a maintenance concept?
- **Q2:** How to implement and organise the maintenance concept?
- **Q3:** How to measure the performance of the maintenance concept?
- **Q4:** What is the overall equipment effectiveness (OEE)?

The objectives of the Diploma thesis are:

- To analyse the state of the art of maintenance concepts and strategies.
- To investigate maintenance service contracts and their advantages and disadvantages.
- To develop a service maintenance concept framework for SMEs.
- To set up a case study in which the developed service maintenance concept framework is adopted.
- To investigate further improvement and adoption possibilities of the developed service maintenance concept.

2 Theoretical Background

Nowadays, companies are facing different challenges. Apart from affordable and cheap production, companies must react quickly and flexibly to changing customer demands, high quality expectations and environmental protection standards. Especially in countries with high wage costs it is necessary to take care of these issues and set a new strategic orientation to ensure the future existence of the company. For this, the term 'lean management' has had a breakthrough and is focusing on avoiding waste in every production unit of a firm. Whereas it is not a method and more a description of a condition, it is focusing on the different types of waste[1]. As the term, 'lean management' focuses on the whole organisation, it is mandatory to consider aspects of the production and its influential factors. Lean production is orientated by the principles of the Toyota Production System (TPS)[2]. However, to achieve the desired goal of lean production, a company can make use of different methods. According to A. H. Mazlan et al. "Lean Manufacturing (LM), employing the concepts of 5S, Total Productive Maintenance (TPM), and Kaizen, keeps machinery producing the same way or better than the day it was received, even after many years of use"[3]. Something that maintenance and lean management have in common is the avoiding of losses which is guaranteed by the function of the equipment and a fluent production process through maintenance. However, the challenge is to decide between the three areas of tension: economy, safety and availability to reduce the costs and to maximise the availability of the equipment. Different maintenance strategies help to find the optimal balance within this triangle. Besides, the strategies of maintenance, the term 'Maintenance' has developed through time and new methods as well as concepts were developed. Whilst the focus was once on breakdown maintenance, it has been further developed to planned maintenance and shifted, on to TPM. At this stage, employees are also considered as part of the maintenance process. The last change started after the millennium. Today's requirements are more than just to ensure the safety and availability, they aim also to improve the equipment[4].

Companies are looking for new possibilities to develop or maintain a competitive advantage. Outsourcing is one option to do so[5]. There are various types of outsourcing strategies and also different providers of maintenance services. This can be further considered by companies that are willing to outsource their maintenance tasks[6].

[1] (Brunner, Wagner, 2016)
[2] (Schmitt, Pfeiffer, 2015)
[3] (Mazlan, An, Halim, Abidin, Aziz, Ridzwan, 2014, p. 2)
[4] (Matyas, 2013)
[5] (Gómez, Parra, 2009)
[6] (Bloß, 1995)

2.1 Lean Production

Lean production means avoiding losses or waste. It is important to understand that lean production is not a method. It is more about describing a condition of a company with a low inventory. Having not too many employees, enjoying an appropriate company size and short product development[7]. Lean production combines the advantages of mass production, like economies of scale and scope, with the benefits of a small craft business which allows for flexible production combined with high quality. Further, it aims to exploit technical and human possibilities to get lean[8]. The following chapter presents the different types of waste and the respective methods for reducing them.

2.1.1 Muda, Mura, Muri – 3M

In the Toyota Production System (TPS) the terms Muda, Mura, Muri are often used together and are defined in KAIZEN. All together they describe wasteful practices that should be avoided to get lean[9]. The idea behind this: in order to guarantee a value creation of a product, minimum expenses and effort in terms of material, parts and working time are necessary inputs. Any effort or expense that extends upon this minimum can be considered waste. In particular the avoidance of idling and defects are crucial to achieving lean production[10]. Possible influences on the key elements: are; human; machine; and material which are shown in figure 1[11].

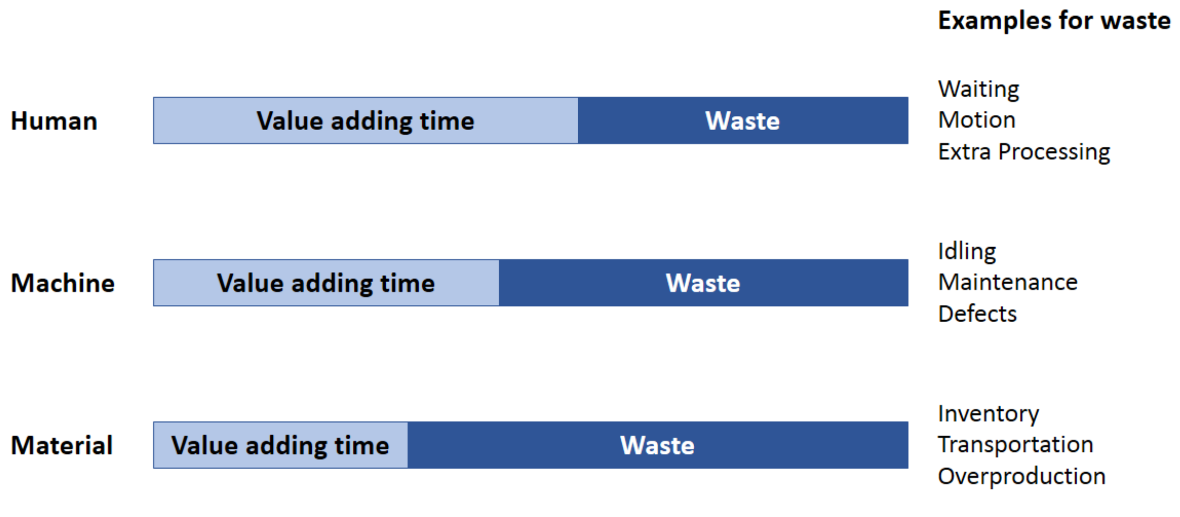


Figure 1: Types of waste for human, machine & material[11]

[7] (Matyas, 2013)
[8] (Sihn, 2011)
[9] (Schmitt, Pfeifer, 2015)
[10] (Brunner, 2014)
[11] (Suzaki, 1989)

Muda stands for wastefulness and considers any activity that requires resources without creating any value. Depending on the literature there are seven[12], eight[13] or nine types of waste. The different types can be seen in Table 1.

Table 1: Types of waste (own depiction) [14]

Type of waste	Description
Overproduction	Producing too much of a product, before selling it
Waiting	Waiting for the previous step in the process
Extra Processing	Activities that are not necessary to produce a product / service
Transportation	Not needed transport or unnecessary long transport ways
Inventory	Inventory that is temporally not needed and sitting idle
Motion	Unnecessary motion of people or equipment due to workspace layout or misplaced items
Defects	Resources to correct mistakes
Non-Utilized Talent	Not effectively engaged employees to the production process
Reinventing the wheel	Good practices that are not replicated or communicated

Muri stands for overburdening and addresses the employees and the equipment. Running at a higher speed by force or more effort can result in technical defects or psychological issues.

Mura represents unevenness in an operation. Unevenness can be caused by internal problems and uneven work pace that might cause the operator to hurry at one task and hold back on the following one.

A simple example to understand the relation of these three wasteful practices is shown in figure 2. It is supposed that a firm wants to transport six tons of material with the support of a truck that is rated for three tons only. There are different possibilities existing on how to operate it. The first one would be to place the whole load in one journey. This would overburden the truck, as it is rated for three tons instead of six (muri). Another possibility is to pile four tons in one cargo and two tons to another one. The first tour is an example of muri again, as the truck is overloaded. It would also

[12] (Matyas, 2013)
[13] (Brunner, 2014)
[14] (Hariharan, 2014)

cause jams at the company or dock that is receiving the goods (mura). The third option would be to make three journeys, each with two tons. This avoids an overload but causes unnecessary means of transportation (muda). The best solution in this cause would be to plan two journeys, each with a load of 3 tons, as it avoids all three wasteful practices[15].

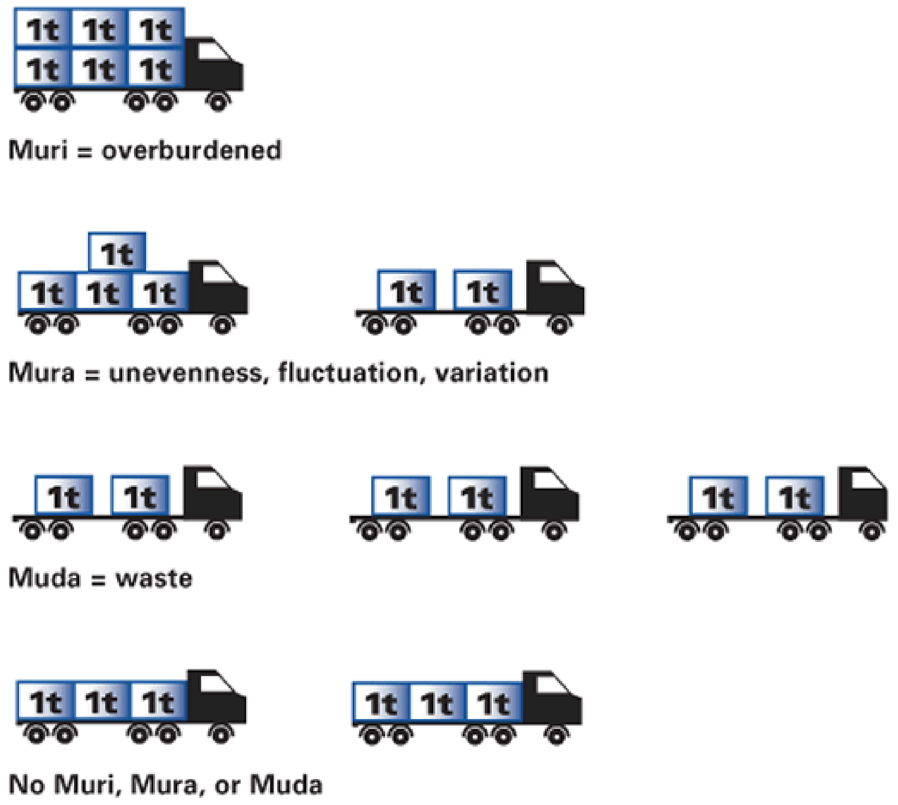


Figure 2: Examples for 3M[16]

2.1.2 Methods of Lean Production

To avoid waste or losses and to get lean, different methods have been invented in the past. An overview of an excerpt of different methods is given in the figure 3.

Nowadays, there are many methods existing to get lean. The focus will be on elements that have a high influence on lean production and its losses[16]. Although, SMED (Single Minute Exchange of Die) or the continuous improvement also known as KAIZEN are methods that have an impact as well. The original equipment manufacturer (OEM) that delivers the machine has no influence to the company's policies and culture. Therefore, the focus is set on TPM, Lean Maintenance and the importantance for the implementation of TPM - 5S.

[15] (Lean Lexicon, 2014)
[16] (Sihn, 2011)

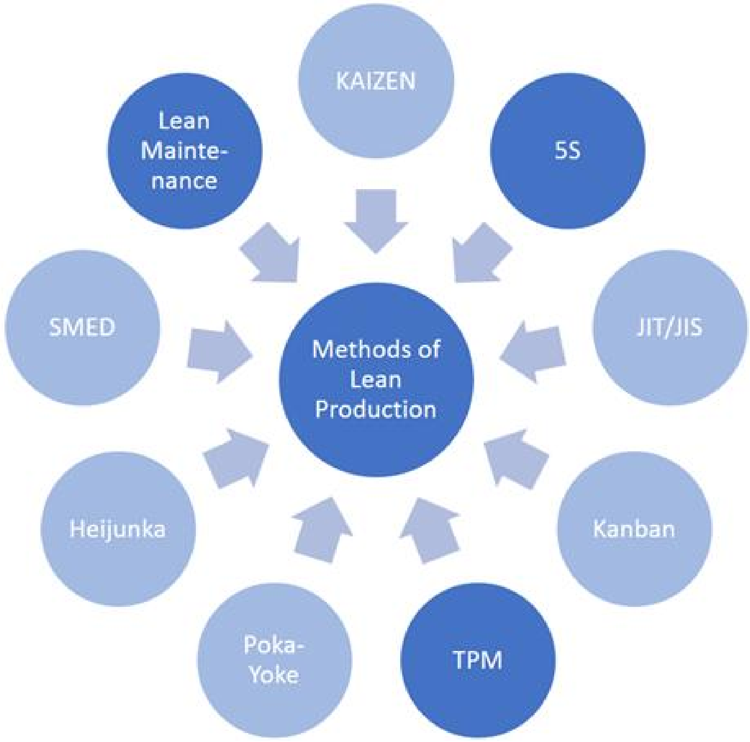


Figure 3: Methods of Lean Production[17] (modified figure)

2.1.2.1 5S

The method '5S' is a technique for continuous improvement. It is described as the foundation on which flow production and visual control are set up[18]. It is meant to be a technique which can improve housekeeping, health and safety standards as well as environmental performance[19]. Additionally, it aims to reduce waste by making use of the so called 5S methodology. '5S' itself is an acronym that stands for:

- Seiri – Sort
- Seiton – Set in Order
- Seido – Shine
- Seiketsu – Standardise
- Shitsuke – Sustain

The basic idea of this Japanese philosophy is cleanliness and orderliness. Those are crucial for a maximisation of quality and productivity[20].

[17] (Sihn, Kuhlang, 2011)
[18] (Hirano, 1990)
[19] (Khamis, Rahman, Jamaludin, Ismail, Ghani, 2009)
[20] (Brunner, 2014)

The basic idea of this Japanese philosophy is cleanliness and orderliness. Those are crucial for a maximisation of quality and productivity[20].

The concept starts with the **sort** part, which is a process of removing all non-essential items from the work area. In particular, work areas that were built up over years can contain tools which are not necessary. These have to be identified and removed from the workplace. Examples would be cleaning supplies, extra tables and items, tools or documents.

The next step would be to **set in order** and describe a process in which the remaining tools and items are organised. The idea behind is to have a place for everything and everything should be in its place, unless it is being used at the moment. In addition, the tools should be as close as possible to the place where they are needed.

After organising the work area, it is time to make it **shine**. This part describes the whole cleaning process of the work area, machines and equipment and keeping it as clean as the machine was when it was delivered. Leaks can be identified in a clean surrounding faster than in a dirty one. Only by identifying these spots the system can be optimised.

The next step is to **standardise** the implemented habits. As soon as a condition of cleanliness is reached it is important to keep it. Otherwise it is lost effort and can be considered as loss. For this, it is necessary to keep the machine clean every single day, by having the same cleanliness at the end of the shift as at the beginning.

Finally, **sustainability** is necessary to make sure that a condition of cleanliness is kept. Periodical checks make sure that the achieved level of cleanliness stays[21].

Benefits of 5S

Besides the simplicity of 5S, it further has other benefits that make it more than just a housekeeping tool.

- Improved Safety – A maintained and organised working area means reducing hazards. Walkways are clear and the working area is clean. With tools being nearby the walkways, losses are reduced as well.
- Improved Quality – As the tools are reduced to the ones that are necessary, the probability of using the wrong one is reduced. By using the correct tools, the

[17] (Sihn, Kuhlang, 2011)
[18] (Hirano, 1990)
[19] (Khamis, Rahman, Jamaludin, Ismail, Ghani, 2009)
[20] (Brunner, 2014)
[21] (Michalska, 2007)

chance of damaging the product or the equipment is reduced which increases the quality of the product.

- Increased Efficiency – The new organisation and cleanliness is increasing the efficiency by avoiding the search for tools or long walkways to them.
- Improved customer satisfaction – The improved quality and efficiency will also increase the satisfaction of the customer.
- Reduced operating costs – The reduction of defects and the improvement of efficiency will decrease the costs that are needed for operating the system.
- Reduction of material waste – The improved quality will reduce any future defects.
- Improved staff morale and happiness – A cleaner and safer environment also increases the motivation and morale of the employer[22].
- Space usage is improved – As unnecessary tools are put away the space is used more efficiently.
- Reduction of defects – Mistakes can be proven faster in a clean surrounding which helps to reduce defects.
- Reduction of inventory – As only the needed tools for the machine are at the workplace, the inventory is reduced[23].

Implementation of 5S

The implementation of 5S is often suggested in a P-D-C-A Cycle[23 24 25].

The plan part considers all parts of the preparation like providing trainings and education, seting-up a 5S council, 5S zones, determining objectives and goals for each 5S phase as well as planning the action plan and launching 5S.

After planning the implementation of 5S, the ideas have to be realized. The actions are described above in the definition of each phase.

The last phase in the 5S philosophy is called standardization. It considers frequently checkings which is also the next step of the P-D-C-A cycle. Internal 5S audits help to get an overview in bigger companies how the 5S is running. Also benchmarks within

[22] (Tisbury, 2013)
[23] (Khamis, Rahman, Jamaludin, Ismail, Ghani, 2009)
[24] (Rahman, 2005)
[25] (Kumar, 2012)

the department and other organization can be completed, to ensure that the established 5S structure remains.

Finally the act stage raises the fundament for continual improvement. The defined goals are compared with the actual objectives and conclusions are derived. Moreover, the staff should be rewarded for the effort and a 5S registration can be considered. However, the Plan-Do-Check-Act Cycle has to be reviews and the process starts all over again. The process is shown in figure 4[26].

A successful implementation requires that every employee understands the benefits of the 5S philosophie and identifies with the idea. If there is no identification by the maintainer, operator or management there is no chance for 5S[27].

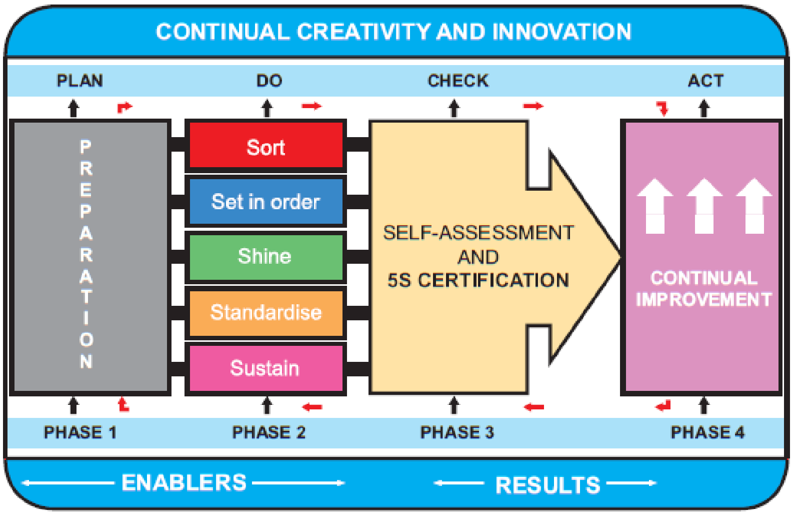


Figure 4: P-D-C-A Cycle of 5S Implementation[26]

Conclusion 5S

The 5S method is a simple tool to structure and organize a company. The cleanliness and organization helps to avoid losses and ensures a more efficient production with a higher quality. The method consists of five phases in which the cleanliness habit is coming to live step by step. For the implementation, the P-D-C-A Cycle is considered as one option that helps to structure the implementation process. However, the 5S method is highly dependent on the staff. For this it is important that every employee understands the benefits and idea of the concept and identifies with it.

2.2 Maintenance

The task of maintenance is the service of the machines and equipment and aims to guarantee the performance and safety of the equipment and machines as long as

[26] (Rahman, 2005)
[27] (Kumar, 2012)

possible. Maintenance is responsible for high equipment availability and preferably low claims costs[28]. Its concepts and strategies have changed over time. Especially, the higher complexity of the equipment and parts made these technologies necessary to find the origin of malfunctions[29]. The strategy defines the ways and rules of when, how and where actions have to take place to ensure fluent production. While the conceptually there has been a shift from a reactionary to a proactive and preventing method from total productive maintenance through lean maintenance as well as smart maintenance to the latest concept: lean smart maintenance[30].

2.2.1 Definition of maintenance

According to DIN EN 13306:2010, 2.1 maintenance is a “combination of all technical administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function”[31]. Maintenance combines the four elements of inspection, preventive maintenance, repair and improvement[29].

An **inspection** is an examination of the conformity of an item. During the inspection relevant characteristics are measured, tested and observed[32]. Different actions can be distinguished:

- Determining the actual state
- Evaluating the actual state
- Assessing the actual state
- Determine the reason for wear-out
- Error analysis
- Initiate further actions and measurements[29]

All actions taken to reduce failure probability are described with the term **preventive maintenance**. The actions are carried out under defined intervals and special criteria. It helps to avoid down times and breakdowns[33] and consists of the following tasks:

[28] (Rötzel, 2017)
[29] (Matyas, 2013)
[30] (Biedermann, 2008a)
[31] (Maintenance – Maintenance terminology, EN 13306:2010)
[32] (Mende, 2007)
[33] (Rötzel, 2017)

- Cleaning (remove foreign and auxiliary substances)
- Conserving (preventive actions against external influences)
- Readjusting (remove mistakes)
- Lubricating (add new lubricant to keep the slippage)
- Complementing (padding auxiliary substances)
- Replacement (replace auxiliary substances and tiny parts)

As soon as a wear-out took place, the faulty unit gets replaced or repaired. These actions are collected under the term **repair**[34]. The difference with preventive maintenance is that the preparation for repairs is more complex and needs physical activities[35].

Finally, **improvement** describes all activities that intend to improve maintainability, safety and reliability without changing the original function. The goal is to reduce shortcomings, weak spots and safety deficits[36].

2.2.2 History of maintenance

Maintenance has been changing since the 40s[34] and 50s[37]. In these years, the change from breakdown maintenance to planned maintenance took place. One or two decades later the maintenance concept changed again to productive maintenance. Here, the responsibility shifted to a maintenance department. Total Productive Maintenance has been developed between 1969 and 1971 in Japan by Nippondenso[34] which was the next generation of maintenance. New computer systems and analytical methods were implemented. Especially, the higher complexity of the equipment and parts made these technologies necessary to find the origin of malfunctions. Competitive elements played an important role as well. Machines had higher utilisation and were set up in a production chain. Breakdowns lead to production stopping in a whole plant. This made it crucial to improve upon the term maintenance once again. The last change started after the millennium. Today's requirements aim at more than ensuring safety and availability, they aim to improve the equipment. The ultimate goal is to change the construction to avoid maintenance. For this, there is a concept of preventive maintenance needed[37]. The figure 5 shows the development of different maintenance concepts.

[34] (Matyas, 2013)
[35] (Mende, 2007)
[36] (Daneshjo, Kravec, 2016)
[37] (Brunner, Wagner, 2016)

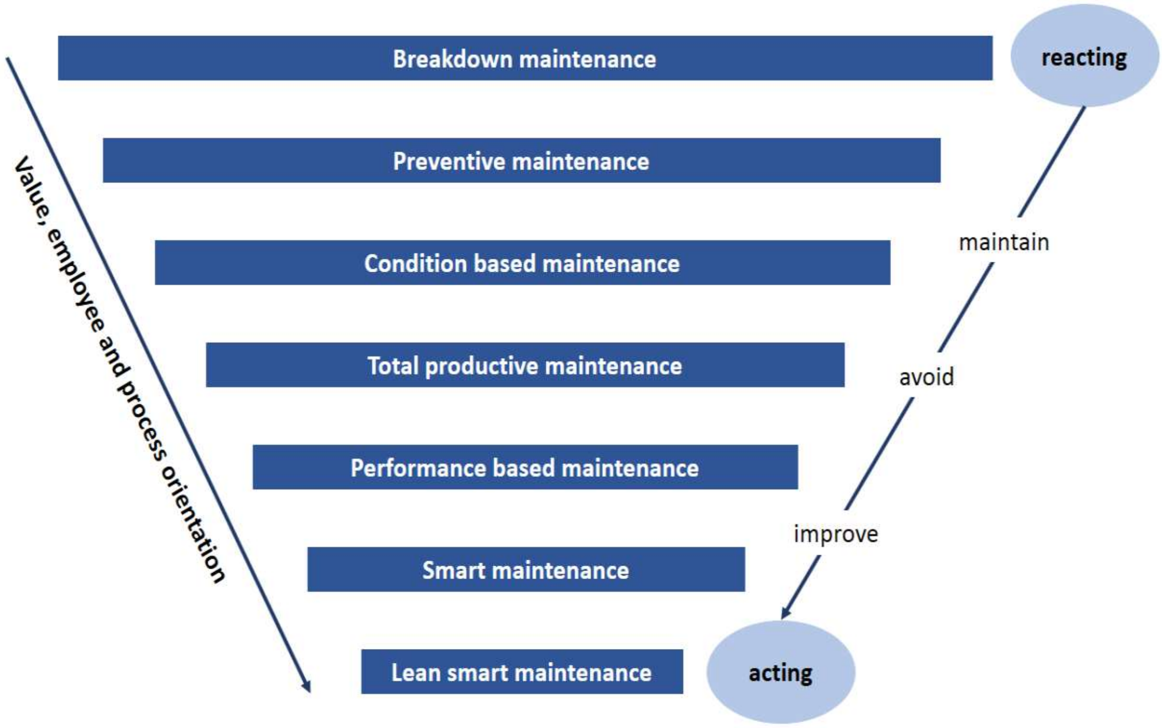


Figure 5: Development of maintenance concepts[38]

2.2.3 Maintenance strategies

Maintenance aims to guarantee the function of the equipment and by this avoiding losses. The maintenance strategy that is chosen depends on the company and its objectives. It defines the ways and rules when, how and where actions have to take place to ensure fluent production. The challenge is to decide between the three areas of tension: economy, safety and availability, to reduce the costs and to maximise the availability of the equipment. The more the production depends on the equipment and the more continuous the production process is running, the higher the impact is on malfunctions or breakdowns. Under these conditions the costs for breakdowns are comparatively high which leads to a higher value being placed on maintenance. Depending on the importance of each part and each machine, an optimal maintenance concept consists of a mixture of the following strategies:

- Run to failure (breakdown maintenance)
- Preventive maintenance (scheduled maintenance)
- Condition based maintenance
- Predictive maintenance

[38] (Biedermann, 2008a)

Run to failure is mainly used for material and equipment which is minimal important to operations. There is hardly maintenance effort put into the machine until the breakdown. Depending on the impact of the breakdown and the costs, this method is preferred for machines which are either redundant or have a low importance for the production process. The problem occurs, if a machine has a breakdown, it has a longer downtime as the defect or the broken part needs to be found, before being able to repair it[39].

The opposite is the so called preventive maintenance. Here, the part or the assembly is being replaced and does not depend on the codition. It is useful, if a risk can be expected towards the environment, safety or the approximate lifetime of the part is known and a run to failure would result in higher costs. To reduce costs of not used equipment the time interval between two actions should be as short as possible. For this, the planning can make use of four different abilities.

1. Average time between two damages

The reason for huge variations in this average can be due to differing origins of the damage. In this case, it is advised to do periodic maintenance activities and different maintenance intervals are needed.

2. Different scattering between usage time

If there are different usage times of the part or machine, it should be considered in the calculation. The minimum design service life counts as a key indicator for the set interval of maintenance.

3. Damage documentation

The data needed for extensive preventive maintenance is often insufficient for new equipment. The available information cannot cover the needed details to plan preventive maintenance. Another aspect is, that practical experience shows that there is often no complete documentation of damages in companies where no IT system is implemented.

4. Insufficient statistical experience

Information for damages are not available everywhere. This leads to a limitation in terms of interpretation. One reason for this can be the occasion, that the pieces are in operation for a short time and there is not much information about the failure. In addition, it is generally not possible to observe different objects at the same time to derive statistically reliable data.

[39] (Matyas, 2013)

Although it is a relatively simple and efficient strategy, it can be more expensive in the long run, as the majority of these inspections are a straight forward pass[40].

A solution for the mentioned problem of high cost might be the so-called condition based maintenance. It is cost saving and reduces work time spent on maintenance due to maintenance actions that depend on the degree of wear of the equipment. Suited observation and measurement systems make it possible to reduce deviations and inform the maintainer in time. The monitoring system can consist of sensors, an online surveillance or an easier method by visual inspections. Besides the reduced costs there are also other benefits existing. The possibility to destroy something during the maintenance is being reduced and by diagnosing possible defect the risk of consequential damages is being reduced as well.

The last strategy is predictive maintenance. The wear cannot always be measured, as it depends on the position in the equipment. Besides these hidden disturbances there can be disorders that need to be found before they occur. Examples could be the risk of bad influence on safety or the environment again. Predictive maintenances are more difficult and can be done by a monitoring system that makes vibration analysis.

As the maintenance strategy depends on the requirements concerning the machine or the part, the strategy varies as well. For this, the idea of reliability-centered maintenance (RCM) might be an option. As most of the equipment failure is not linear there is a need for a process that analyzes the possible failures for each part and derives from a customized maintenance strategy. However, to be able to customize the maintenance strategy, the maintenance process must be understood completely. Moreover, a gapless documentation and analysis of breakdowns are required[40].

2.2.3.1 Lean Maintenance

Lean maintenance is adopting lean principles into the maintenance process which means generating a desirable outcome by minimising inputs or losses. This is done by “planned and scheduled maintenance activities through total productive maintenance (TPM)” that “is the foundation of lean maintenance”[41]. To achieve a lean maintenance, different lean activities can be considered, including 5S, TPM, OEE and also Kaizen, Poka-Yoke, Jidoka, JIT, Kanban or value stream mapping is possible. As lean production aims to reduce losses, lean maintenance has similar benefits and has a positive impact on the above-mentioned losses[42].

[40] (Grothus, 1994)
[41] (Matyas, 2013)
[42] (Smith, 2004, p. 18)
[42] (Jones, Womack, 2003)

As lean maintenance builds up on TPM the question arises to what the difference is between lean production and TPM. Lean production is a philosophy to reduce waste, while TPM is a method for increasing productivity. However, many companies implement first TPM before lean production is considered[43].

2.2.3.2 Total Productive Maintenance

The program Total Productive Maintenance (TPM) aims to increase productivity, quality and the moral of employees. In former times, preventive maintenance was not considered to add a value. Nowadays, it is crucial for a longer life cycle of a machine in an industry. One approach to increasing the life cycle is TPM which optimises the overall equipment effectiveness (OEE) by eliminating downtimes and losses. Further, it supports autonomous operator maintenance by day-to-day activities[44]. This attitude requires a fundamental change in company's culture. The mindset that a certain maintenance group is responsible for their equipment needs to be applied to each individual responsibility of those working in the plant[45].

Definition and elements of Total Productive Maintenance

Total Productive Maintenance is a concept geared around ensuring optimal use and the prevention of breakdowns of production equipment, factors and plants. The concept has been developed to ensure a 100% availability of the machine. The difference between classical maintenance concepts and TPM is found in the inclusion of employees into a continuous improvement process. The goal of TPM is to maximise the total equipment effectiveness through a total maintenance system.

TPM includes different divisions like engineers, managers, maintenance employees and includes employees from all hierarchical levels. For TPM there are three elements which are crucial: the total effectiveness, total maintenance system and the total participation of all employees. An overview is given in the figure 6.

- Total Effectiveness – Describes the pursuit of economic efficiency and earning.
- Total Maintenance System – Includes the prevention of maintenance, the responsibility of maintenance and the improvement of maintenance.
- Total Participation of all employees – Employees of all hierarchical levels and divisions are taken into account

[43] (Araspour, Karimi, 2009)
[44] (Desai, Gohil, Shah, Singh, 2013)
[45] (King, 2009)

To reach the ambitious goal of maximizing the equipment efficiency to 100 %, a value called overall equipment effectiveness is being considered that helps eliminating the six big losses[46].

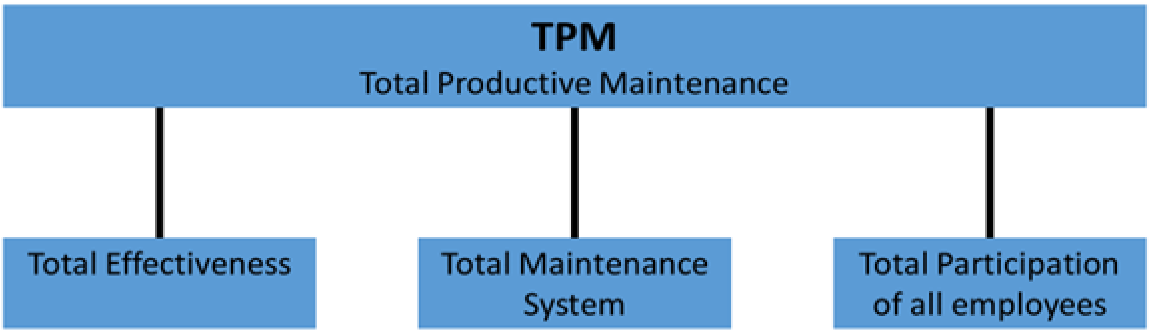


Figure 6: Total Productive Maintenance[46] (modified figure)

TPM in the western world - TPEM

When TPM was developed in Japan, it included the participation of every single employee. The core idea of putting the maintenance and the employees into focus however, lead to problems in non-Japanese companies. For this, the western world developed another concept, which takes the idea of TPM and sets the focus on the machine and plants, instead of the maintenance and employees. This is justified by the fact, that machines have the highest bound capital, besides buildings and land ownership. Since, the Return on Assets (ROA) is a common measurement for the financial performance of a company, it has to ensure that the availability, utility and performance of the operating system is kept high. The TPM process by Total Productive Equipment Management (TPEM) realigns and restructures the management of the operating system. This leads to a shift of the key components to the following three elements that are further essential for the key performance indicator overall equipment effectiveness (OEE). The OEE will be introduced later in this paper.

- Utility of the equipment system
- Performance of the equipment system
- Availability of the equipment system

[46] (Brunner, 2014)

Like TPM, TPEM consists of three components as well. These components are autonomous maintenance (AM), planned maintenance (PM) and equipment management (EM). Based on the analysis of the OEE and the set goals in each section, it is possible to make use of these three components to understand important influences and possibilities to increase the equipment's utility, performance as well as availability. Figure 7 gives an overview of the components and their elements[47].

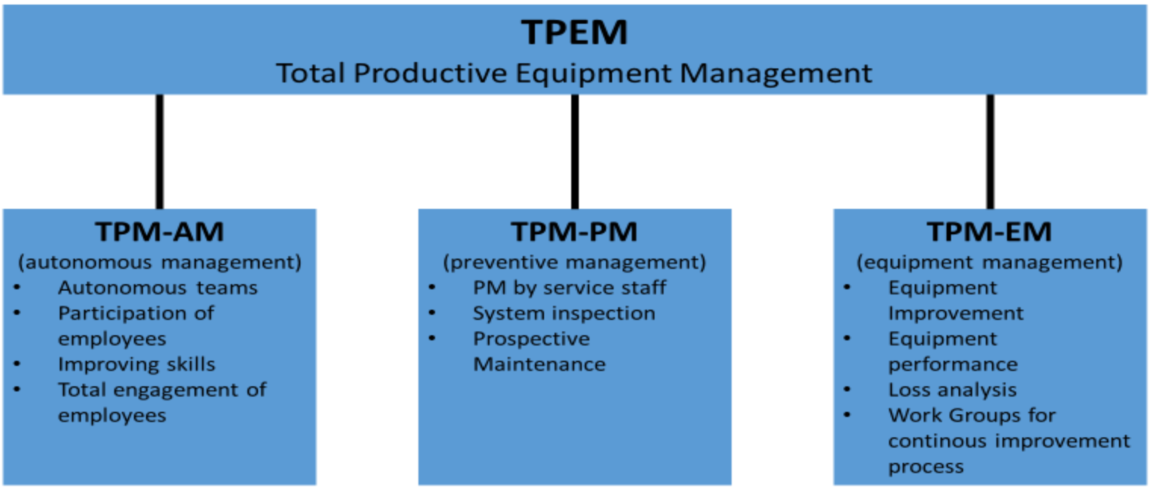


Figure 7: Components of TPEM[47] (modified figure)

TPM-AM – Autonomous Maintenance[47]

Although autonomous maintenance is listed first, it shall be noted that it does not have to be implemented first for successful TPEM implementation. The difference between the autonomous maintenance in TPEM and TPM is that each company is being encouraged to find its own functional approach to autonomous maintenance. The focus lies with the individual participation of staff. The staff shall be enabled to fulfil the necessary maintenance and inspection tasks through maintenance training. Depending on know-how and motivation, eligible employees have to be selected for the tasks.

Hartmann suggests training incorporating hierarchies. The entire personnel working on the machine should get the basic training (TQ-1). Depending on each company it is advised to analyse exactly what the employees who are working on the machine need to know for daily production. The next level is already limiting the number of employees being trained. It is focusing on most of the staff working on the machine. This level is more about specific knowledge and maintenance. It is recommended that employees who have passed the specific training (TQ-2) should also get a higher income based

[47] (Hartmann, 1998)

on their higher knowledge and qualification. The last and highest step would be the specialisation training (TQ-3). Only few employees would reach this level and would be qualified to ensure difficult set-ups and adjustments of the machine.

Every autonomous team would consist of different skills. Everyone who is working at the machine has equal basic knowledge whilst some employees focus on maintenance and inspection whereas the highest qualified employees support and/or operate the setting up of the machine. This method supports teamwork and increases the autonomy of employees as well as it increasing their engagement.

A company has different options how to organise the training. As already mentioned, each firm can individually decide on how much autonomous maintenance they want to implement. It should nonetheless be taken into consideration that higher input guarantees a better outcome. The more highly educated and autonomous the employees are, the more motivated they will be and the more efficient the equipment will run. All of these aspects will lead to a higher output of goods and quality. To enable these benefits the company has to assess their employees on their capability for handling different tasks, thus determining who will receive which training. The next question that arises is where would the company find such training. Feasible options might be through a consultancy firm, a local school or even through retired employees who return for the purpose of sharing professional experience. Another option is the OEM, which has a particularly high interest in offering special training in maintenance. The OEM is an expert in assembling the machine and selling training on how to maintain the machine through which in turn the OEM can utilise after sales. in this way the manufacturer would be able to bind the customer whilst satisfying his needs. By undertaking training sessions the manufacturer would also be able to get feedback from the personnel working on the machine on a daily basis. This feedback could be used to improve the quality of the machine even further. At the end of the training the employee should do a final test in which the acquired knowledge should be applied. If the employee passes the test, he or she will receive a certificate of the course. The company should also collect the information about the successful participation, to get an overview of the qualification of the employees and their potential.

After the trainings, the employees are able to detect mistakes and performance issues. The element that TPM and TPEM have in common is that of motivation of the employees. Just by teaching them how to maintain a machine there is no motivation guaranteed. For this, Hartmann suggests promoting a special type of motivation which he calls ‘my machine’. The idea behind this concept is that employees who identify themselves with their work and particularly with their machine take more care of it. The machines look cleaner, work better and are better maintained. In addition, the employees are proud of their machine which motivates them to work with it. There are different ways of making use of this concept. Some companies put the name and the picture of the responsible employees on the machine, others have a chart with two axes. On the horizontal axes are the different types of trainings and, on the vertical are the names of all machine operators. As soon as one operator passes their training he or she receives a medal on the chart showing which trainings he or she completed successfully. Of course, there are many other possibilities existing to increase the motivation of employees. Those mentioned here are only a small introduction into this topic and shall merely give an idea into what a company can do to motivate their staff. This is crucial for the implementation of TPM-AM as it cannot be successful if the employees do not participate.

In a nutshell, TPM-AM is a way of reducing costs, increasing performance and spreads responsibility among the employees. For this, good planning is needed, along with the correct training and motivated employees.

TPM-PM – Planned Maintenance[49]

Keeping the operating system in a good condition is necessary to guaranteeing a good production process. Maintaining the equipment helps to satisfy this need. Planning the maintenance process supports the production flow and thus the performance of the equipment. There are different types of planned maintenance:

- routine planned maintenance (cleaning, lubrication, inspections, testing, small repairing, service, adjustments)
- extensive planned maintenance (disassemble of machine, different tools, higher qualification needed, planning downtimes, higher qualification needed, testing)
- overhaul of the machine (complete disassembly, transport of the machine to another spot, high knowledge, participation of producer, new calibration, many tools, time intensive)
- preventive maintenance (predict the behaviour of the machine by different measurements: vibration analysis, megohmmeter, spectrographic oil analysis, thermographic analysis and many more)

Depending on the difficulty of the maintenance, the latter can be either the task of the operator (Type I activities) or maintainer (Type II activities). The company needs to structure tasks so to avoid misunderstandings which can further occur in the understanding of maintenance. As mentioned before, there are different types of maintenance. To avoid these problems, the different types of maintenance need examples and definitions.

[49] (Hartmann, 1998)

As soon as the activities are allocated, the planning can start. There are two types of strategies a company can have in PM. On the one hand, a firm can optimise the maintenance process. On the other, it can aim to transfer as many tasks as possible from the maintainer to the operator to support the autonomous maintenance at a later stage. An effective PM-system contains ten steps:

1. Determining the operating system data

This information can be found in the inventory list and consist of the type, number, name, position, logbooks of the machine etc.

2. Defining the PM-Types of activities and urgencies

The mentioned types above are defined at this part. Furthermore, the urgency of the equipment is structured to guarantee a maintenance if there is a bottle neck of employees.

Urgency 1: Breakdown of the machine leads to shutdown of the plant (e.g. harming the security of the employees)

Urgency 2: Failure of the machine leads to shutdown of an area

Urgency 3: Failure of a machine that is not critical for the production process or has some shutdowns from time to time

3. Developing a PM check list

There are two types of check lists. One contains simple tasks that can be checked during the operation of the system like checking the lubrication, tightening a bolt or measure conditions with tools. The tasks are clustered into, for example, daily, weekly and monthly tasks. The other check list contains works that have to be completed during a shut down like cleaning the engine. The aim is to allocate as many tasks as possible into the checklist that is concluded during the operation process.

4. Developing a PM work instruction

A PM work instruction consists of different maintenance that repeats periodically over the course of months, or either quarterly or annually. Each work instruction is bound to an operating system and encompasses a list of tasks and the needed time. These tasks are more complex and are generally the responsibility of the maintainer.

5. Developing PM routes

Developing PM routes helps to avoid losses due to detours. The maintenance is planned in tours from machine to machine and ensures that the employers are provided with the necessary tools.

6. Developing PM schedules

The actions enable the company to set up a schedule for PM. The time that is needed for maintenance and planned shut downs is taken into consideration. It ensures the setting up of plans for each machine and enables more dynamic planning. For example, tasks that are completed monthly and quarterly at a machine can be accomplished at once to avoid two shut downs.

7. Making use of a machine logbook

Besides the importance for the OEE that will be described later on, a logbook helps to manage the maintenance and improvement of the operating system. It contains information and data from maintenance and parts needed for it as well as the time and costs needed to maintain the equipment.

8. Making use of bar codes

Taking down information like parts used or machines maintained, it is always possible to make mistakes. Making use of bar codes avoids mistakes of writing something down manually and speeds up the whole process. As soon as the maintainers starts with the maintenance, they can read the bar code and the system takes down the beginning time itself. The parts that are used for the maintenance can have bar codes as well. As soon as the job is done the employees read in a bar code again. The system knows immediately when the work has started, ended, how much time was taken as well as which part was needed. This helps to organise the logbooks and the costs.

9. Developing a reporting system

There are two types of reports: the control report and the interim report. The control report represents the accuracy in which PM is fulfilled while the interim report is about the benefits and progress of PM. Elements of each report could be:

Control report:

- PM fulfilment (task done compared to tasks planed)
- PM performance and productivity
- PM costs (machine, maintainer, supplier etc.)

Interim report:

- Lost hours for machines, departments, plants (delivered by production department)
- Trend of lost times
- Times between break downs
- Benefit of improved production time correlated with costs

10. Implement a PM organisation

The described concept needs someone who is supporting it. For this a group of employees or a division is needed to manage PM. Depending on the size it can be sufficient if it is one employee or maybe it is necessary to set up a new department. However, the structure should be as easy as possible to ensure fast and simple implementation.

TPM-EM Equipment Management[50]

The difference between TPM-AM and TPM-PM is that TPM-PM needs the experience and the creativity instead of manual work as it is about thinking work. The idea is to build circles in which problems are being analysed and improvement suggestions will be given. The participation of the employees increases their motivation as well. The idea is to implement continuous improvement action teams (CATS) or creative action teams (CAT) on a voluntary basis. The group of people should be diverse and consists of engineers, maintenance employees and employees that work every day with the machine. The size of the group should be between five to seven people and needs a coordinator or moderator.

However, the group needs data and information to be able to analyse problems and potential issues. There are different sources existing. Hartmann named four of them, the OEE-Loss-analysis, analysis of the operational equipment state, machine logbooks and the error sheet. The OEE will be described later, as it is more complex and is analysing systematically the performance, utility and quality that influences the effectiveness. The analysis of the operational equipment state is a more a subjective tool.

The employees rate the equipment in three different categories:

1. Reliability
2. What can be expected from the machine

[50] (Hartmann, 1998)

3. General condition
    a. Look / cleanliness
    b. User-friendliness
    c. Security / surrounding

Although the OEE delivers a systematic analysis of the most important elements the analysis of the operational equipment state helps to get further information about a general condition or subjective opinions which the OEE is not able to capture. Especially the subjective opinion of the employees can show the need for improvement and will support the process later on.

Machine logbooks give information about the history of production. When did mistakes occur and how often did they occur. If there is no logbook the company can make use of error sheets. The sheet is simple and consist of three major questions:

1. What happened? – Description of incidents
2. Why did it happen? – According to your opinion, why did the mistake occur
3. What can be done against it? – How to avoid similar incidents in the future

The advice is that the CATS take place at periodic appointments. Each appointment needs a clear structure of each point and a protocol. For the analysis of the problems and the process for solving the problems the participants can make use of the M7-Methods or the Q7-Methods.

To ensure the motivation of the employees the results of the team should be presented to the management. Furthermore, the team should be evaluated to assure their motivation. There are also concepts advocating monetary prizes for good ideas[50].

Benefits of TPM

Implementing TPM is a long process and takes some effort. For this, some empirical benefits are presented in table 2. The data is taken from companies who won the TPM-award. On the one hand, it explains the enormous benefits and on the other hand it shows the possibilities of TPM[51].

[51] (Brunner, 2014)

Table 1: Benefits of TPM (modified table)[52]

Productivity	Increasing of working productivity by 50 % Reducing disturbances by 98 %
Quality	Reducing processual mistakes by 90 % Reducing defects by 70 %
Costs	Reducing maintenance costs by 30 % Energy saving by 30 %
Storage	Reducing inventory by 50 % Increasing turnover speed by 100 %
Safety / Environment	No accidents No pollution
Moral	Increasing number of suggestions for improvements to 230 % Doubling group meetings

2.2.3.3 Smart Maintenance

According to the European Technology Platform on Smart Systems Integration, "Smart Systems are able to sense, diagnose, describe, qualify and manage a given situation, their operation being further enhanced by their ability to mutually address, identify and work in consort with each other. They are able to interface, interact and communicate with users, their environment and with other Smart Systems"[53].

With the implementation of Internet of Things or in the German area the so called 'Industrie 4.0', it is possible to connect equipment, machines and systems with the internet. This so called cyber-physical system is a mix of local information, information processing and bigger systems, that evaluate the information. Based on this evaluation the systems work autonomously and control, observe or regulate the process in real time. The systems are able to reduce the amount of primary and secondary resources by optimising the consumption[54]. These decisions need data and information. In 2012 a survey has shown that almost two third of the questioned companies see a competitive advantage in the use of data. Especially the new means of analysis, new types of data and real time information have been considered as the biggest advantages. Half of the surveyed companies admit that customer goals are most important followed by 18 % of operational optimisation. All of the drivers are shown in figure 5[55].

[51] (Brunner, 2014)
[52] (Brunner, 2014)
[53] (EpoSS, 2015, p. 2)
[54] (Broy, 2010)
[55] (Romero-Morales, Schroeck, Smart, Tufano, 2012)

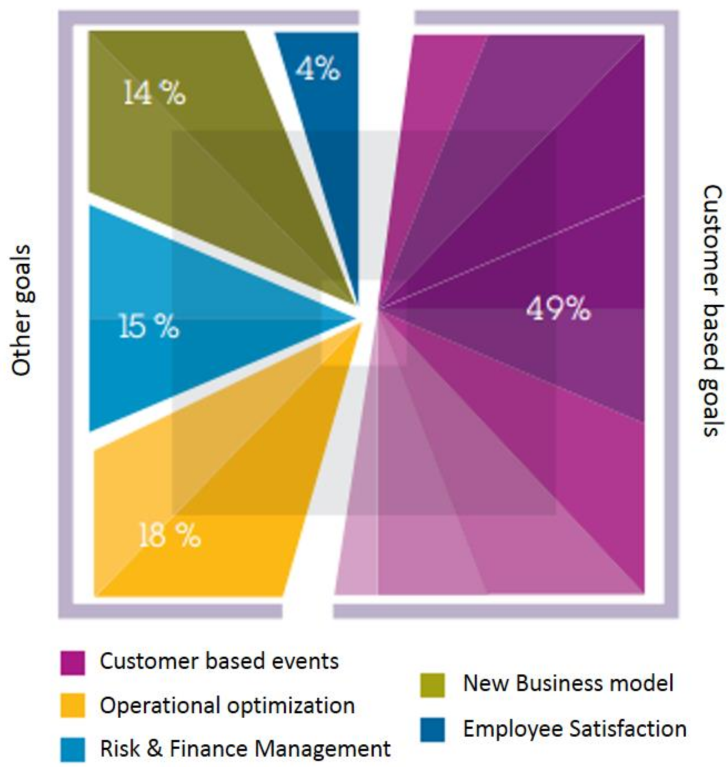


Figure 8: Big data drivers[56]

The increasing connection and complexity of the equipment and the increasing demands of flexibility have an influence on the failure risk of the equipment. Temporal calculations estimate that the costs of failure will increase the amount of costs three to five times because of failures or breakdowns. These demands make it necessary to evolve the maintenance concept and strategies to a new one which is able to stand up to future challenges. However, the growing amount of data makes it necessary to standardise, structure, analyse and combine the collected data[57]. This leads to a new task of maintenance: the development of interoperable systems. It is not sufficient anymore to just collect the data from different sources. The data has to be connected and processed in order to allow digital systems to make use of it[58].Therefore, a company that wants to work in the industrial revolution of the internet of things needs to adjust the maintenance system to that of a smart factory. For this, it needs a strategical improvement of maintenance technologies, data management and knowledge management[59].

56 (IBM Global Business Services, 2012)
57 (Acatech, Henke, Kuhn, 2015)
58 (Manyika, 2015)
59 (Broy, 2010)
60 (Bernerstätter, Kinz, 2016)

2.2.3.4 Lean Smart Maintenance

The state of the art in maintenance is in Lean Smart Maintenance (LSM) along with predictive maintenance. This new approach aims to optimise the maintenance even more than traditional preventive maintenance concepts by making use of the benefits of the internet of things[60]. It is a combination of the two described concepts Lean Maintenance and Smart Maintenance. It aims to reduce losses as well as increasing the availability and reliability of the equipment. The concept contains different elements, which Biedermann implemented into a P-D-C-A cycle. The cycle starts with the planning of the goal system by evaluating the value added contribution. The contribution can either be the maximum principle or respective the increase of output/outcome (e.g. through Overall Equipment Effectiveness, Net Equipment Effectiveness (NEE) and Total Equipment Effective Equipment Productivity (TEEP)) or by the minimum principle and decrease of maintenance costs. From there, the above-mentioned maintenance strategy is into derived from the 'do' stage. The control part is comparing the real and the planned values. A core element is the weak point analysis that helps to identify deviations and sets a basis for adjustments. The weak point analysis focuses on two parts. One part is the analysis of the maintenance and preventive maintenance methods concerning their effect, risk, reliability and losses and takes the OEE into account. The second part, includes the infrastructure and the environment that also have an influence on the maintenance strategy. Finally the adjustments take place in the 'act stage' to improve the system, before the cycle starts all over again[61]. The LSM approach aims to improve the efficiency of maintenance management systems by setting priorities to the optimisation of process organisation, maintenance planning, spare part management and total productive management. Further, the effectiveness of data management, knowledge management, employee qualification, maintenance strategy optimisation and life cycle orientation, predictive and proactive maintenance is being improved[62].

Maintenance and the Internet of Things

In the last twenty years the internet connected billions of humans. Nowadays, the 'things' are included as well. Machines are getting tools that enable them to communicate with their environment. Those tools can be cameras, sensors and actuators. An embedded software allows the generation, collection and analysis of data during the operation of a machine. The internet of things permits the machine to not only send the information around the world, but further enables communication between the different devices.

[61] (Biedermann, 2016)
[62] (Bernstätter, Kinz, 2016)

Manufacturers and operators of big machines manage and observe their devices from long distances. If problems occur, it is costly and time consuming to find the origin of the problem. If the origin is located, the procurement of spare parts is even more challenging. The delivery time for the spare part results in a longer breakdown time of the machine. To remedy this, it is of great use for the persons responsible to be able to obtain the details of a problem in a timely and cost effective way, when complications arise. This would help to support the preventive maintenance and to evaluate potential actions which might avoid a problem. There are different software tool support predictive maintenance. They monitor in real time and collect data concerning energy consumption, temperature, the usage of resources, capacity utilisation and many more. This supports the acceleration of the whole maintenance process and reduces breakdown times as well as increasing equipment efficiency[63]. The first step in maintaining machines over big distances - also called 'remote maintenance' - is to create an infrastructure of connectivity and digitalisation. Elements that are able to communicate and collect the crucial parameters need to be embedded into the system[64].

As mentioned in the introduction, a focus on SMEs is needed. The challenge SMEs are facing is that there is not possibility to create a new production environment and buy a new plant. It is more important to make use of the available equipment and adjust it to enable the use of all benefits concerning the 'Internet of Things' (IoT). The latest research of the Technical University Darmstadt and the so called project 'Effiziente Frabrik 4.0' which is analysing the different opportunities SMEs have. They developed different implementation scenarios for hardware and software to enable SMEs to exploit the benefits of IoT.

Data is crucial for maintenance and needed to avoid losses. This can be supported by Making parts and equipment available to information carriers. Collecting the data and process this information is from fundamental importance. In future these tasks will be automated without any interruption. For this, the automated collection of data needs to be extended to a communication system between objects and actors after defining all the necessary objects that influences the parameters. The digitalisation of information and data enables the employer to perform paperless quality assurance thus reducing mistakes. As the collection of information is not only dependent on one parameter - rather from different impacts - it is suggested that operating material is included in the process of data collection as well. Thereafter, this information can be transferred to various batches. A cheap possibility would be to make use of Radio Frequency IDentification (RFID) parts to be able to track the products and the resources and ingredients.

[63] (Rückert, 2016)
[64] (Michels, 2016)

In a later stage, this information can be used for digital value stream mapping. This newly gained transparency of the process can then be used to optimise and understand the whole process as well as to reduce costs to increase the return. The following key parameters in particular have a strong impact and support the transparency, consistency, reliability and topicality:

- run through time
- cycle time
- setup time
- layover
- inventory
- OEE
- quality
- productivity

To ensure that information is being collected and provided at the same time, classical communication systems are no longer valid. The classical communication system is a horizontal one that provides information from one stage to another. This needs to be extended to a vertical system, that enables communication between products, processes and machine elements. For example, external sensors can be implemented in the machine or products to help in tracking them and understanding the process.

All these methods focus on physical elements. An exceptional role in the IoT affects the employee since there are no statements yet concerning the future of humans in these processes. One possibility might be to implement the employee into the process and create flexible and intelligent plant assistance systems. The employee could then help to identify and assist the system. For example, in the case of a breakdown, the machine would provide information regarding the broken part and the employee could collect the information to get the necessary part and exchange it. Furthermore, it is possible to provide needs-based information to each employee. By connecting an employee with an ID, the system would recognise on its own who is getting what information. This avoids an information overflow and accelerates processes[65].

The closer the vision of IoT is coming, the more it shows that there is enormous potential. However, this potential relies on data. The question arose to whom this data belongs to and temporally it seems that it belongs to the customer. Experiences in

[65] (Anderl, 2016)
[66] (Ganz, 2016)

early case studies show that the customer is willing to share this data anyway, when there is a possibility to receive an added value service[66].

Implementation of Lean Smart Maintenance[67]

For the implementation of lean smart maintenance a dual procedure model as one possibility is being considered. The model starts with an evaluation and classification of the equipment. The evaluation should take two elements into account, the monetary and the non-monetary elements. Based on the analysis you receive an image of the critical machines which is necessary for the implementation of LSM. The evaluation and classification can be completed with different tools, depending on the demands, e.g. bottleneck analysis or risk assessment.

Building up on the results of the evaluation the dual paths of the analysis can start. The one patch contains the lean elements, while the other path takes care of the smart elements that are data driven.

2.3 Outsourcing of maintenance services

Companies are looking for new possibilities to develop or maintain their competitive advantage. Outsourcing is one option to do so. Besides the benefits of reducing costs and focusing on core competencies there are also some risks like the loss of knowledge and control[68]. There are different types of outsourcing strategies for maintenance that reach from an optional balance of maintenance needs via having for a special type of maintenance a contract partner to a complete outsourcing of maintenance services. Whilst there are different types of outsourcing, there are also different providers for maintenance services[69].

2.3.1 Advantages and disadvantages of maintenance outsourcing

In general, outsourcing has advantages and disadvantages. The argument that underlines outsourcing the most is that a company can focus on its core competencies while outsourcing minor important skills, e.g. maintenance. For this, the company receives a provider who provides the service and saves resources like humans, capital

67 (Biedermann, 2016)
68 (Gómez,Parra, 2009)
69 (Bloß, 1995)
70 (Campbell, 2006)
71 (Tho, 2015)
72 (Alexander, Young, 1996)
73 (Halvey, Melby, 2005)
74 (Jharkharia, Shankar, 2007)

or tools [70]. A collection of different advantages and disadvantages of outsourcing maintenance is shown in table 3 [68 71 72 73 74].

Table 2: Advantages and Disadvantages of outsurcing the maintenance[75]

Advantages	Disadvantages
- Reduction costs, at the same quality to employ a supplier more specialized - Restructuring costs, changing fixed costs by variable costs (as service provided) - Obtaining rapid budget by selling assets - Improvement of quality, for higher specialization - Access to outside expert knowledge - Standardization and access to scale economies - Flushes resources for other purposes - Improves company focus - Improving management of difficult functions to handle - Optimizing routine tasks - Share the risk by flexibility of demand with the supplier company - Provides legal guarantee for services - Relationships developed between financial aspects and levels of service - Starting point for changes in the organization - Speed through reengineering	- Unfulfilled or questionable expectations - Changes in the quality for breach of agreements on services, either by the knowledge or capabilities of the supplier company - Loss of knowledge or skills through transfer to the - supplier - Loss of control over the externalized functions - Dependence by the supplier could cause adverse - consequences for the client - Loss of security by transferred staff to the supplier - Public and internal opinion for outsource jobs to another company - Loss of motivation for staff involved in the service

2.3.2 Different types of outsourcing maintenance[75]

The decision in which way maintenance is being outsourced is depends on the maintenance capability of a company. There are three different types of outsourcing maintenance existing.

1. **Optional balance of maintenance needs**

This type of outsourcing is the most flexible one. A company can focus on its daily business and covers the need of maintenance. In case there is a capacity constraint it makes use of foreign maintenance service employees. This strategy ensures that there are less costs for idling, as the maintenance is quicker and more flexible.

2. **Permanent outsourcing of special maintenance services**

[75] (Gómez,Parra, 2009)

Another option is the permanent outsourcing of maintenances services that need a special skill, knowledge and tools. Besides, the costs for maintenance trainings and company equipment as well as resources are being reduced and transferred to the service provider.

3. **Complete outsourcing of maintenance services**

The complete outsourcing enables the providing company to fulfil the whole maintenance tasks. This leads to a situation in which the producing company does not need any maintenance employees anymore. Aside from this, the billing is more transparent and easy as the services can be more easily structured as well as getting more transparent.

2.3.3 Provider of maintenance services[76]

There are different maintenance service providers for a company at the market to ensure efficient and effective production.

Customer service of the equipment manufacturer

The employees of the equipment manufacturer are in general specialists. To diversify their portfolio and differ from competitors, manufacturer frequently offer maintenance services. The challenge for the manufacturer thus exists in not selling too many maintenance services in equipment, as their reputation might suffer from this. For this, there is a trend of offering complete service packages for the whole maintenance work.

Maintenance and repair by specialised third parties

Third party companies often focus on certain tasks of maintenance and cleaning. Like the OEM they tend to take care of all maintenance activities. Since these companies are specialised in maintaining the equipment they can guarantee high quality service.

Local craft industries

Local craft companies consist mainly of skilled workers. They can maintain and inspect in most cases only limited amounts of problems or errors. Having cooperation with these providers is more common in regions where there is poor infrastructure.

Outsourced maintenance company

Another method is the outsourcing of maintenance and founding of a new company. By this the company provides services to their own subsidiary and is more flexible concerning performance. Furthermore, the newly founded company is able to offer services to competitors, with which money can be earned as well. However, the know-

[76] (Bloß, 1995)

how, skill and equipment for being able to maintain the machines must be kept constantly on a high level to ensure the capabilities of maintenance.

3 State-of-the-Art

To set up a service providing maintenance concept for it is crucial to measure the performance of maintenance and the concepts[77]. Moreover, the different maintenance concepts need to be investigated regarding their implementation into an organisation. Finally, the different types of maintenance outsourcing possibilities and the relevant maintenance service contracts have to be further considered.

3.1 Maintenance productivity and performance

The second largest single component for facility operation costs are typically maintenance costs. To support stakeholders of the core business, maintenance strategies and their performance need to be measured, monitored as well as optimised[77]. An indispensable characteristic of measurement systems are ‘Key Performance Indicators (KPI)’[78]. Several performance indicators that address the maintenance performance and the cost effectiveness have been developed through time. Depending on the objective and strategy, the performance indicator has to be defined for each task[79].

3.1.1 Performance measurement systems

The definition of a performance measurement system is the set of metrics used to quantify the efficiency and effectiveness of actions. The provided information helps to make decisions, either by the management or by the employees[79]. The so called ‘Maintenance Performance Measurement (MPM)’, that helps to reduce the expenses has been defined in 2006 by Parida as “the multidisciplinary process of measuring and justifying the value created by maintenance investment and taking care of the organisation’s stockholders’ requirements viewed strategically from the overall business perspective”[80]. With the IoT, including its sensors, actors and RFIDs, there is a new source of data and information available. The use of the enormous amount of data and information by this source is merely possible with a lean key performance indicator cockpit[79]. According to Cable and Davis, KPIs need to be identified and tracked to be able to compare the current state with a baseline point of reference, from which to derive improvements and deviations[78]. Besides financial aspects, some researchers like Amaratuga et al. and Brackertz claim, that KPIs were focusing primarily on financial aspects.

[77] (Gregory, Neely, Platts, 1995)
[78] (Róka-Madarász, 2011)
[79] (Bernerstätter, Kleindienst, 2015)
[80] (Cable, 2004, p. 20)

The demand was to connect indicators to the contribution they made to the organisation's strategy, its goals and the job satisfaction[81 82]. The most important performance measurement systems that take other aspects into consideration are: [83]

- Tableau de bord
- Performance pyramide
- Balanced Score Card (BSC)
- Performance prism

3.1.2 Maintenance Performance Measurement Systems

To be able to improve maintenance and reduce costs, it is essential to analyse the data. Besides, the top management should be involved as well as the commitment of them supports the process. The maintenance performance measurement system should be aligned to the company's vision. One possibility in setting up a maintenance performance measurement system is to question the success factors and to establish an indicator system based on these influences. To identify them it is advised to answer the following questions: [81]

- Who are the most important stakeholder of maintenance?
- What are the most important strategic goals in maintenance?
- What is necessary that maintenance is successful and when is it?
- Which aspects can be improved?
- What are the strengths of maintenance?
- Where are bottle-necks?
- What are costs and success drivers?
- What are the biggest challenges in maintenance?
- Which Key Indicators need to be reported periodically?

The next step would be to identify the key indicators. This should be done in groups of different people and through brainstorming. One way to put different indicators together is the above mentioned 'Balanced Score Card (BSC)'. It considers different perspectives like the financial, customer, internal processes, innovation and learning perspectives[81]. It respects both tangible and intangible elements of the business for the first time[84]. The disadvantage of the BSC exists in not keeping the total

[81] (Brackertz, 2006)
[82] (Amaratunga, Baldry, Sarshar, 2000)
[83] (Bartolini, Raffoni, Silvi, Visani, 2015)
[84] (Augenbroe, Park, Pati, 2009)

effectiveness in mind. The total effectiveness takes the internal and the external effectiveness into account.

Another approach is to determine the issues that can be related to maintenance performance measurement the following questions should be answered: [85]

- "What indicators are relevant to the business and related to maintenance?
- How are the indicators related to one another and how do they take care of the stakeholders' requirements?
- Are the 'Maintenance Performance Indicators (MPI)' measurable objectively and how do the MPIs evaluate the efficiency and effectiveness of the organisation?
- Are the MPIs challenging and yet attainable?
- Are the MPIs linked to the benchmarks or milestones quantitatively / qualitatively?
- How does one take decisions on the basis of the indicators?
- What are the corrective and preventive measures?
- When and how does one update the MPIs?"

The design of a maintenance performance measurement system can be divided into three stages:

- Integration of maintenance from shop floor to strategic level
- Multi-criteria MPM system
- Implementation of MPM system

As mentioned before, the maintenance strategy is based on the company's business strategy, stakeholder's requirements as well as corporate strategy and objectives. The defined objectives are converted into measuring criteria at the functional level. The integration of maintenance from shop floor to strategic level shall ensure the participation, identification and integration of the lower hierarchical levels. By linking the MPM system through the functional and hierarchical levels and connecting the top, middle and bottom level with each other, the employees are able to speak the same language. This guarantees an understanding of each employee, why and what for, the data is being collected. The definition of measurements for monitoring and controlling can be extremely complex. Depending on the structure and the size of a firm the complexity can increase. One possible example of a hierarchical level of an organisation and the measurement of different criteria is shown in figure 9.

[85] (Augenbroe, Park, Pati, 2009, pp. 25 - 26)

The top level represents the top management and considers strategic or corporate issues . The second level that represents the middle management considers tactical subjects and the third level is responsible for operative topics.

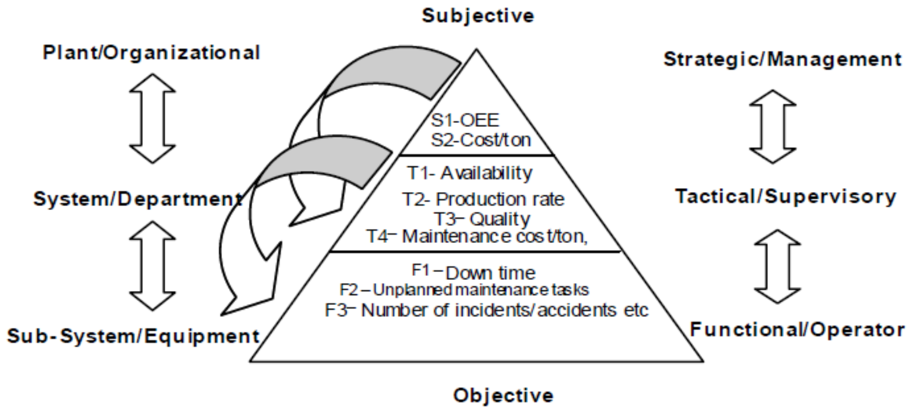


Figure 9: Hierarchical levels of an organization[86]

The MPM system has some requirements. It should take different MPIs into account that represent financial and non-financial indicators. Further, it should be flexible and transparent, user-friendly and allowing to be linked directly to the organisational strategy. The classification of MPIs into a multi-criteria MPM system supports the provision of total maintenance effectiveness[87]. Parida et al. classified the MPIs into seven categories: [88]

1. Equipment related indicators
2. Cost related indicators
3. Maintenance task related indicators
4. Learning and growth related indicators
5. Customer satisfaction related indicators
6. 'Health, safety and environment (HSE)' related indicators
7. Employee satisfaction related indicators

After testing the reliability of the system, whether it provides the correct measures consistently over time and its validity, the **implementation of the MPM system** can be initiated. The implementation is critical, as issues like fears, politics, lack of active management commitment and involvement, communication and dissemination all prevent successful implementation of an MPM system[87]. A possible multi-criteria

[86] (Kumar, Parida, 2009)
[87] (Augenbroe, Park, Pati, 2009)
[88] (Cable, 2004)

framework for MPM that considers different criteria in different hierarchical levels is shown in the figure 10

Front-end process
-Timely delivery
-Quality
-HSE issues

External Effectiveness
-Customers/ stakeholders
-Compliance with regulations

Internal Effectiveness
-Reliability
-Productivity
-Efficiency
-Growth & innovation

Back-end process
-Process stability
-Supply chain
-HSE

Hierarchical level / Muli-criteria	Level 1 Strategic /Top management	Level 2 Tactical/Middle management	Level 3 Functional/ Operational
Equipment/ Process related	- Capacity utilization	- Availability - OEE - Production rate - Quality - Number of stops	- Production rate - Number of defects/rework - Number of stops/downtime - Vibration & thermography
Cost/finance related	- Maintenance budget - ROMI	-Mintenance production cost per ton - Maintenance/ production cost	- Mintenance cost per ton
Maintenance task related	- Cost of maintenance tasks	- Quality of maintenance taska - Change over time - Planned maintenance task - Unplanned maintenance task	- Change over time - Planned maintenance task - Unplanned maintenance task
Learning growth & innovation	- Generation of a number of new ideas - Skill improvment training	- Generation of number of new ideas - Skill improvement training	- Generation of number of new ideas - Skill improvement training
Customer satisfaction related	- Quality complaint numbers - Quality return - Customer satisfaction - Customer retaintion	- Quality complaint numbers - Quality return - Customer satisfaction - New customer addition	- Quality complaint numbers - Quality return - Customer satisfaction
Health, safety & Security, environment	- Number of accidents - Number of legal cases - HSSE losses - HSSE complaints	- Number of accidents/incidents - Number of legal cases - Compensation paid - HSSE complaints	- Number of accidents/ incidents - HSSE complaints
Employee satisfaction	- Employee satisfaction - Employee complaints	- Employee turnover rate - Employee complaints	- Employee absentees - Employee complaints

Figure 10: Multi-criteria framework for a MPM system[89]

3.1.3 Key performance indicator

Through the time there have been developed many performance indicators that addresses the maintenance performance and the cost effectiveness. There are different sources for KPI collections. For example, Pati et al. collected the most important key indicators that exist in 2009[89]. A more detailed and clustered collection has been made in 2010 by Sarel Lavy et al. who considered the different types and categories of KPI's as well. The categories consists of financial indicators, physical indicators, functional indicators and survey-based indicators. The overview is shown in the following figures 11 - 14[90].

89 (Parida, 2006)
90 (Dixit, Garcia, Lavy, 2010)

Indicators	Description	Units
Operating costs	All costs related to facility operation, such as insurance, air conditioning, ventilation, overhead and wages, energy, fire protection, lifts and escalators, repair and maintenance, security, cleaning and garbage, sundries, and other expenses and fees	$US (or equivalent) per: (1) Unit area; (2) Person; (3) Employee; or (4) Product
Occupancy costs	Total cost associated with building occupancy, from building occupation to disposal. It includes real estate and personal property taxes, insurance for the building and its contents, depreciation and amortization costs, etc. This may also be considered a subset of "operating costs"	$US (or equivalent) per: Unit area; Person; Employee; or Product
Utility costs	Monthly or annual cost of utilities, including electricity, fuel oil, gas, steam, water, sewage, etc.	$US (or equivalent) per unit area
Capital costs	All costs required to purchase and extend building property, to procure plant and equipment, and to operate the business or organization	$US or $US (or equivalent) per employee
Building maintenance cost	Costs for labor (in-house or contracted-out) and materials required for building monitoring, inspection, repairs, maintenance, and response to service requests	$US (or equivalent) per unit area
Grounds-keeping cost	Costs for labor (in house or contracted-out) and materials required for landscaping, storm water management, and parking lot or garage maintenance	$US (or equivalent) per unit area
Custodial and janitorial cost	Costs for labor, personnel, supplies, and equipment used for providing janitorial and custodial services	$US (or equivalent) per unit area
Current replacement value (CRV)	An estimated cost of restoring the building to its original condition and function. It includes the costs for materials, labor, equipment, architectural and engineering fees, construction management, and other contingencies	$US (or equivalent)
Deferred maintenance, and deferred maintenance backlog	Cost of maintenance of property, plant and equipment that is postponed from a facility's operating budget cycle due to financial constraints. It is measured by conducting condition assessment surveys of existing property, plant and equipment, and by determining the amount of funds required to restore back to a condition of "as good as new"	$US (or equivalent)
Capital renewal	The budget required for performing major renovations in the building, its systems, subsystems, and components	$US (or equivalent)
Maintenance efficiency indicators (MEI)	Indicates the efficiency with which maintenance activities are implemented	MEI values can be divided into three ranges: low, reasonable, and high, based on the actual investment in maintenance, compared to the actual performance of the building
Facility condition index (FCI)	Represented by the ratio between the total cost of deficiencies to the CRV, or by the ratio between the costs of Deferred Maintenance to the CRV	Percentage of CRV
Churn rate and churn costs	Represents the process of moving a group of employees and/or equipment within a period of time (per month or year)	Expressed as percentage of total average employees in a specific time period or in currency ($US or equivalent)

Figure 11: Financial indicators[91]

[91] (Dixit, Garcia, Lavy, 2010)

Indicators	Description	Units
Building physical condition – quantitative: Building Performance Index (BPI)	Indicates the physical-functional state or condition of a facility in terms of building components, systems and processes	Measured as a 100-point scale where a score greater than 80 points represents the building and its performance as good or very good; a score of 70 to 80 points indicates marginal condition, which requires some preventive maintenance measures; a score of 60 to 70 points indicates the deterioration of the building components and system, which requires preventive and breakdown maintenance; a score of less than 60 points indicates poor condition of the building
Building physical condition – qualitative: general building maintenance in: (1) building physical condition; (2) sanitary, plumbing and storm water; (3) mechanical services; and (4) lighting and electrical	Includes maintenance in terms of routine repairs, major and minor repairs and replacements in: (1) building; (2) sanitary, plumbing and storm water systems; (3) mechanical systems; and (4) lighting and electrical systems	Measured on a scale of good, fair, poor, and unsatisfactory based on condition assessment
Property and real estate	Includes real estate area and provides an estimate of owned versus leased area in order to know what fraction is owned and what is leased	Area in sq. ft and fraction of leased or owned area in % of total real estate
Waste	Total waste generated for disposal, waste to landfill, hazardous waste, cost of waste disposal, and amount of waste recycled or reused	Volume per year or month, $US (or equivalent) per year or month, ton per month & $US (or equivalent) per month; reused or recycled waste: percentage of total waste generated; disposal cost: $US (or equivalent) per volume
Health and safety	Includes an estimation of condition of employees' health and safety and organization's compliance with applicable codes related to the health and safety of employees	Employees' number of accidents per year, number of lost work hours, number of workers' compensation claims
Indoor environmental quality (IEQ)	Measured in terms of indoor pollutants, thermal comfort, noise, light, and ventilation; thermal comfort: air temperature, mean radiant temperature, humidity, and air speed; indoor air quality: fresh air distribution, restriction of mass pollution (gases, vapors, micro-organisms, smoke, dust, etc.); day lighting and views: views and natural day light through windows.	Each parameter is measured in its respective units of measurement
Accessibility for disabled	Provision for disabled and preparedness of facility to accommodate special needs of handicapped people	Measured on the basis of level of accessibility of the facility for disabled individuals
Resource consumption – energy: (1) energy use: total facility energy use; or building energy use; (2) net energy consumption; (3) annual energy consumption; (4) total natural gas consumption; (5) building electrical consumption; or (6) building electrical demand, demand intensity, or peak electricity demand	(1) Total energy consumed by entire facility, including stored fuels or gases; energy consumed in the process of heating, ventilation, and air conditioning, lighting, domestic hot water, plug loads, and other building energy use. This does not include process energy (energy consumed in manufacturing, industrial, or commercial activities) (2) Total facility energy use minus facility energy production (includes energy production and energy savings as a result of using energy star rated equipment and employing energy efficient efforts) (3) Total consumption of energy per year (4) Total natural gas consumed by the facility (5) Total building electricity consumption (6) Building electrical demand is the maximum amount of electricity that a building consumes at a given time Demand intensity is the maximum electricity consumption per unit area at a given time.	(1) kWh, Btu or Joules (2) kWh, Btu or Joules (3) kWh or kVA, kWh or kVA per unit area per hour, or kWh or kVA per person per hour (4) kBtu per unit area, kBtu per person, or therms per year (5) kW or kVA (6) kWh; kW per sq.ft or kVA per sq. ft; kW or kVA
Resource consumption – water: (1) water consumption; or (2) net water consumption	(1) Total building water use (2) Total water consumption minus reused, recycled and treated water	Volume per month, volume per product
Resource consumption – materials: (1) material consumption, or (2) net material consumption	(1) Quantity of total material used in the process of operation and/or production (2) Total material consumption minus waste, reused, and recycled material	Cubic feet or tons or any appropriate unit of weight
Security	Describes the condition of security and effectiveness of security measures in the facility or organization	Number of security incidents per year
Site and location	Characteristics of facility's site in terms of size, location, safety, sound and quality, accessibility, contours, preservation and development	Points are given on the basis of: Size: length to width ratio; location: proximity to homes and other community facilities; safety, sound and quality: site is away from dangerous facilities like freeways, railroads, dams, airports, industries, traffic intersections and electric lines,

Figure 12: Physical indicators[92]

[92] (Dixit, Garcia, Lavy, 2010)

Indicators	Description	Units
Productivity	Measures productivity in terms of: (1) occupant turnover rate; (2) absenteeism; or (3) occupants' satisfaction and self-rated productivity	(1) turnovers per year (2) absentees per year, or (3) survey-based data
Parking	Availability of parking spaces	Number of parking spaces per person
Space utilization	Measures over-used and under-used spaces, adequacy of space, and proper space management	Survey-based data
Employee or occupant's turnover rate	It is the ratio of number of employees turned over in a period of time to the total average number of employees in that period	Ratio (number of employees turned over to the total average number of employees in a given period of time) and number of turnovers per year
Mission and vision, and Mission Dependency Index (MDI)	Facility's preparedness to fulfill its mission. MDI indicates priority of mission in projects and funding	MDI is measured using a 100- point scale, usually represented by the following colors: blue (0-40), green (40-55), yellow (55-70), orange (70-85), and red (85-100, most critical)
Adequacy of space	Suitability of space for the proper functioning of the facility. Sufficiency of space for various building operations, maintenance, equipment, and other supportive systems	Survey-based data

Figure 13: Functional indicators[93]

Indicators	Description	Units
Customer/building occupants' satisfaction with products or services	Measures the ability to deliver quality products and services to customers, effectiveness of their delivery, timeliness, and overall customer satisfaction with building, building services, and building systems	Customer survey-based data
Community satisfaction and participation	Community involvement, interaction and favorability, and satisfaction among the community	Survey-based data
Learning environment, educational suitability, and appropriateness of facility for its function	Appropriateness of a facility to perform its functions in terms of functional, spatial, and psychological aspects	Survey-based data
Appearance	Exterior and interior visual qualities, harmony with surroundings, scale and proportion of spaces, and visual stimulation of the facility	Survey-based data

Figure 14: Survey-based indicators[93]

93 (Dixit, Garcia, Lavy, 2010)

Depending on the goals and the strategy of an organisation, the performance indicator has to be defined for each task. According to definitions, the productivity is defined as a ratio of the two elements input and output. As soon as the output is higher than the demanded input a company is productive. Resources like money, labour, materials, equipment, tools and plants are considered as input, which is needed to generate a certain output like services or products. A further specification is made with the term efficiency and effectiveness. If a firm is able to reach with the same amount of input a higher output than someone else, the company is producing more efficiently than the other one. Whereas efficiency measures the relationship of outputs to inputs and queries whether things are completed correctly, effectiveness considers the question of whether the right things are finished, and measures the output conformance to a specific characteristic. However, productivity is the combined measure of, efficiency and effectiveness[94]. To measure the effectiveness of a system, it is mandatory to quantify the productivity and identify possible areas in which improvements can be made. This makes measuring the maintenance performance crucial for a company[95].

Besides the numerous KPI's shown above, it is important for an optimal production quantity to have an appropriate maintenance and safety strategy. Important measures therefore are: [96]

- "Total cost of maintenance / total production cost;
- A (availability) = (planned time - downtime)/planned time;
- P (production rate) = (standard time/unit)x(unit produced)/operating time; where; operating time = planned time – downtime;
- Q (quality rate) = (total production – defective quantity or number)/total production;
- Mean time to repair (MTTR) = sum of total repair time/number of breakdowns;
- Mean time between failure (MTBF) = number of operating hour/number of breakdowns;
- Maintenance breakdown severity = cost of breakdown repair/number of breakdown;
- Maintenance improvement = total maintenance man-hours on preventive maintenance jobs ÷ total man-hours available;
- Maintenance cost per hour = total maintenance cost/total maintenance man hours;
- Man power utilisation = wrench time/total time;

[94] (Kumar, Parida, 2009)
[95] (Ben-Daya, Raouf, 1995)
[96] (Kumar, Parida, 2009, pp. 22 - 23)

- Manpower efficiency = time taken/planned time;
- Material usage/work order = total material cost/number of work order; and
- Maintenance cost index = total maintenance cost/total production cost.“

One of the most important effective KPIs in performance measurement is the so called ‘OEE’. It is the multiplication of the above-mentioned variables A (availability), P (production rate) and Q (quality rate)[97]. The maintenance key performance indicators or also called the ‘Maintenance Performance Indicators (MPI)’ depend on the way in which the MPM has been developed. The MPI has to fit to the process input and the process output and help support financial reports, monitoring the performance of employees, the overall equipment effectiveness, safety, health and environmental ratings. Only once the process is carried out can support be ensured[98]. To identify the KPI or the MPI for a maintenance performance measurement system, the KPI should have the following abilities: [99]

- Shows development and success indicators
- Has an objective value
- Easy to understand
- Are practicable
- Good balance between effort and benefits

3.2 Maintenance Concepts

A maintenance concept is described as a set of directives that describe the maintenance which hast to be carried out. The larger and complex a system, the more important gets a maintenance concept[100]. The applied concept to a technical system is dependent on its demands. There are different maintenance concepts which have to be distinguished. For instance there is Reliability Centred Maintenance, Business Centred Maintenance, Total Productive Maintenance and Lifecycle cost approaches[101].

[97] (Augenbroe, Park, Pati, 2009)
[98] (Ellington, Kumar, 2000)
[99] (Bernerstätter, Kleindienst, 2015)
[100] (Gits, 1997)
[101] (Waeyenbergh, Pintelon, 2002)

3.2.1 Reliability Centred Maintenance

‘Reliability Centred Maintenance (RCM)’ is originally based in the aircraft industry. The concept is aimed at achieving improvements in terms of safety or operation procedures. Successful implementation will decrease the costs and increase the machine uptime[102]. Moubray designed RCM, which has been invented in the aircraft industry for the general industry and defined it as: “a process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context”[103]. RCM starts defining the functions of each asset. This means, that the users determine what they want their assets to do and what must be done so that the assets are capable to do it. Therefore, functions need to be clarified.

The primary functions summarise the main purpose of the asset while the secondary functions stand for the expectations of the assets, such as safety, economy, protection, environment and many more. In general the users of the assets have the best knowledge about functions and can contribute their knowledge about the assets. If done properly, this stage takes up to a third of the time, a whole RCM analysis would usually take.

Derived from the defined functions, the possible function failures are being deducted. This so called ‘Failure Modes Effects and Criticality Analysis (FMECA)’ is questioning the circumstances that lead to a failed state and after questioning what events lead the assets to get into the failed state. The events that lead to the failure state are the so called failure modes. The collection of failure modes includes generally failures by deterioration, wear and tear or human errors. Not only the collection of modes is important, the origin of the modes is important to know as well. As soon as a failure mode appears, the process suggests the creation of a so called failure effect. This effect contains information such as:

- “what evidence (if any) that the failure has occurred
- In what ways (if any) it poses a threat to safety or the environment
- In what ways (if any) it affects production or operations
- What physical damage (if any) is caused by the failure
- What must be done to repair the failure”[104]

The next step is the analysis of the failure consequences. An average industrial undertaking yields between three and ten thousand possible failure modes. Each failure has an effect on the organisation. In particular, the consequences are the reason why an organisation aims to reduce or avoids failures.

In conclusion, RCM consists of three major phases. It starts with the failure findings, which is based on the function definition. The next step is the redesign, which includes built-in capabilities to adjust elements or make modifications. The last element is the so called no scheduled maintenance or as above mentioned the run to failure. This phase is only valid if a maintenance task has no environmental or safety consequences and a proactive task has a positive influence on the total costs. This leads to less waste and a focus on failures that need to be prevented based on safety, environmental or economical reasons[105]. However, the analysis of failure consequences is quite complex. The average industrial undertaking yields between three and ten thousand possibilities. Moreover these failures might originate in common cause, organisational response, type of failure and other reasons. Another issue is the delay of consequences by failures that occurred earlier, without having a direct impact. The effect on the whole plant, its structure, equipment and assets can be a disadvantage as well. The different elements might have different locations, ages, technical systems and different technologies. All these elements increase the complexity of the analysis, which makes the RCM often too expensive in general industries in which maintenance is rather an economic problem. In conclusion, this maintenance concept can be applied to high-tech and high-risk industries, where reliability is an issue[106].

3.2.2 Business Centred Maintenance[106]

'Business Centred Maintenance (BCM)' focuses on maximising the profitability through maintenance. It is a concept developed by Kelly, who aims to ensure the best combination of plant items and maintenance activities. Similar to the RCM approach this concept requires data about workload, forecasts, production plan, production process, expected availability of the system and many more. To be able to implement BCM correctly, it requires even more information than the RCM. However, the difference with RCM is the concentration on maximising the profitability instead of environmental or safety issues. The advantage of this concept is that the maintenance objectives are translated from business objectives and the maintenance concept is derived from these objectives.

102 (Waeyenbergh, Pintelon, 2002)
103 (Moubray, 1997, p. 8)
104 (Moubray, 1997, p. 10)
105 (Moubray, 1997)
106 (Waeyenbergh, Pintelon, 2002)

3.2.3 Total Productive Maintenance[107]

As mentioned in chapter 2.2.2 History of maintenance, the latest element of maintenance, ‘Lean Smart Maintenance’ is assembled on ‘Lean Maintenance’ that is structured on TPM. However, TPM is more a maintenance strategy than a maintenance concept. It does not provide decision making rules in basic maintenance policies, like other concepts do. In chapter 3.5 we take a closer look at the strategy, how to test the feasibility of TPM and how to implement it.

3.2.4 Life cycle cost – approaches (LCC)[107]

Maintenance concepts respect the optimisation of maintenance costs over the life cycle of the equipment. Life cycle approaches consider costs for installation, operation, maintenance, modification, commissioning and replacement. The maintenance concept considers the whole life cycle of a product, as well as the design and customer appeal benefits and allows a positive influence on the market security of the product.

Besides the benefits, it takes high expenditures to gather the necessary information and to implement the concept because of the uncertainty, forecasting demand, cash and time constraints as well as the product life.

3.2.5 Conclusion[107]

In literature there are different maintenance concepts existing. Depending on demands and issues, the choice for one concept might differ. Each concept has different advantages and challenges. A complete overview of the different mentioned concepts above is given in figure 15.

Concept			
RCM	BCM	TPM	LCC-approaches
Advantages			
Traceability	Accuracy	Increased productivity (improvement of operations and workplace)	Improvement of the designer-user interface (engineering approach)
Cost savings	Business centred approach	Increased quality (TQM-link)	Life cycle cost is of central importance
Rationalisation	Integrated auditing possibilities	Cost reduction (reduction of the six big losses)	Correct adaptation brings considerable benefits in most cases
Plant improvement		Increased moral, safety and environmental care	Feedback of information on design
Education			
Involves operators & maintainers		Involves the operators	Full integration (ILS/LSA)
Disadvantages			
Complexity	Complexity	Not really a maintenance concept	Rather theoretical management philosophies
Extensive need of data	Extensive need of data	No decision rules for basic maintenance policies	Difficult implementation, life cycle cost analysis is complex (cash constraints, time constraints, uncertainty of forecasting demand and life cycle)
Focus on ‘reliability’		Cost and profits are not taken into account	
Does not fully recognise that proper maintenance is also an economic problem			Less structured (collection of procedures rather than unambiguous standard method)
No concept improvement mechanism available (no feed-back)			

Figure 15: Overview of maintenance concepts[107]

[107] (Waeyenbergh, Pintelon, 2002)

3.3 Feasibility analysis of TPM

As mentioned above, the latest element of maintenance, ‘Lean Smart Maintenance’ is assembled on ‘Lean Maintenance’ that is structured on TPM. To be able to automise maintenance and avoid losses, there is a need to understand and optimise maintenance. As a first step, the concept of TPM and its most important key performance indicator OEE shall be considered and, if possible, the implementation of TPM.

The core elements of TPM are the employees and the equipment. Of course, the feasibility analysis has to focus on these two elements. Furthermore, the temporal level of maintenance needs to be rated, as the TPM program builds upon the information collected during. The typical feasibility analysis has been clustered by Hartmann into seven steps which will be introduced in the following chapter. Based on these steps the company would be able to implement TPM.

3.3.1 Evaluation of temporal performance & condition of operating systems[108]

The evaluation of the effectiveness will be completed with the OEE. If there is no data available yet, it is recommended to observe the machine for a defined amount of time. The observer will have to prepare time studies at the machine and gather information regarding idling, breakdowns, change overs, quality issues and many other influencing factors as mentioned above. A suitable document for the analysis is shown in figure 16.

The minimum amount of time for which a machine should be observed is four hours. Depending on cycle times and the frequency of losses the observing time can be extended up to 24 hours. Even this cannot be sufficient and the logbook is needed to gather more reliable information. However, overall there is a valid and reliable database after four to eight hours and even longer investigations will not change the percentage of losses. The OEE is the most time intensive element of the feasibility analysis and further the most important one for the improvement TPM-EM. Furthermore, it is proof for the need of TPM, as most of the measured OEE are less than the assumed value.

As mentioned above the OEE considers the whole effectiveness with planned down times, holidays and breaks. The real measurement would be the TEEP as it correlates the most with the return on assets.

[108] (Hartmann, 1998)

Data collection Sheet for OEE

Page ____ from ____
Cycle Time ___________
Date ________________

Machine Name: ______________ Machine Number: ______________ Product: ___________ Observer: ___________

Start	End	Supl. Nr.	Ilding and Stops (Reasons)				Breakdowns (Reasons)				Mainte-nance	Speed loss	Scrap	Amount / Pieces	Comments
Total															

Figure 16: Data Collection Sheet for OEE[109]

3.3.2 Evaluation of employees[109]

The generation of the needed data to evaluate the employees is always challenging, because of special data per employee. Work councils are often afraid that this data will be used against employees. However, to evaluate the best employees for each task it is advised to gather the following information.

I. Needed skills per task

II. Available skills of employees

III. Difference between needed skills and available skills

IV. Possible trainings to fill the gap

V. Learning ability (including the school degree of employees)

VI. Evaluating the motivation of each employee

VII. Changes of work tasks of employees (the more often employees want to change their division or work, the more they are demotivated)

As all this information is not easy to gather it is recommendable to gather as much as possible. If some information cannot be made, it should be eliminated entirely. The Human Resource division will be able to support with providing some of the information.

109 (Hartmann, 1998)

3.3.3 Evaluation of performance and results of maintenance[110]

The next step is the evaluation of the maintenance of the equipment. The focus is on the performance and the results of the way in which the machines are maintained. For this the temporal amount and type of maintenance for each machine should be documented. The evaluation can be documented with a standardised sheet which is shown in figure 17. In addition to the introduced sheet, the logbook can be also used. The actual stage analysis can be utilised to define a target maintenance situation. If there is only a small percentage to fulfil the PM, it is an indication of a lack of motivation and engagement for PM.

Assessment of actual maintenance

Machine Name: ______________________ Date: ______________

Machine Number: ______________________ Employee: ______________

	Tasks	List available	Schedule available	% degree of fulfilment	Performed by	Report available	Comment
1.	Daily cleaning	√	n/a	70%	operator	no	Better process needed
2.	Weekly cleaning	√	no	60%	op/main	no	Unknown distribution of work
3.	Lubcrication	no	no	75%	maintenan.	no	Schedule needed
4.	Daily PM	√		60%	maintenan.	no	Operator wants to do this
5.	Weekly PM	√	√	60%	maintenan.	yes	
6.	Inspektion	no	no	?	maintenan.	yes	No schedule
7.	Forward maintenance	√	√	50%	engineer	yes	Wants to do the maintenance
	Etc.						
a)	Estimated expenditure time for disturbances			80%			Reduce!
b)	Estimated expenditure time for PM-Work			5%			Too low
c)	Estimated expenditure time for further planned maintenance			15%			More needed
	Total			100%			

Figure 17: Assessment of actual maintenance[110]

3.3.4 Evaluation of the cleaning condition[110]

It is assumed that a dirty production line / plant and no discipline are not able to produce a high quality product with high performance.

3.3.5 Evaluation of the company culture[110]

The culture of the company has an influence on the success of TPM. Since, its results depend on the employees. For this, the climate should be investigated and the below mentioned questions taken into consideration:

Are there teams? Do they work? Is there a team spirit? Is there cooperation between employees? Does my management empower employees? Are my employees motivated and engaged? Is there quality management with goals?

[110] (Hartmann, 1998)

3.3.6 Elaborate costs, profit and return on investment from TPM[111]

This step is required if the top management should still be needed to be convinced of TPM. Therefore, a comparison of costs and profit is needed.

Costs for TPM can include:

- Training time
- Development of training material
- Costs for equipment improvement (difficult to guess at this point)
- Costs for TPM employees
- Costs for team meetings (during TPM-EM)
- PR for TPM

Profit from TPM contains:

- Cost reduction
- Increasing productivity
- Less Idling/Break downs
- Postpone the need for new machines
- Less scrap

Through dividing the profit by the costs, the return on investment would result.

3.3.7 Building a Baseline[111]

The Baseline is an overview of the temporal situation. It includes the whole data collected in the feasibility analysis. This data is being sorted and graphically like charts presented. The purpose of the Baseline is to elaborate upon the benefits of TPM in two or three years.

3.3.8 Organization of feasibility analysis[111]

Collecting, analysing and structuring the data needed is time intensive and requires experience. For this, it is advisable to assemble a team for data collection. The team should consist of various members. Like the circles, the team should consist of at least six employees, two operators, two maintainers, one engineer and one group leader.

[111] (Hartmann, 1998)

Furthermore, the team is supported by the TPM-manager and the human resource department. Additionally, it is advised to involve the work council.

The first step of the feasibility analysis will be to train the participating team in all their activities to the next days. This includes the purpose, content, organisation and time schedule of TPM as well as the OEE-analysis.

To ensure a smooth process, a schedule is built up to organise the progress, controls and goals. The timetable is highly dependent on the number of machines included in the TPM process, the size of the company and their team. However, a duration of eight weeks is set as the ideal time frame. A possible schedule is shown in figure 18.

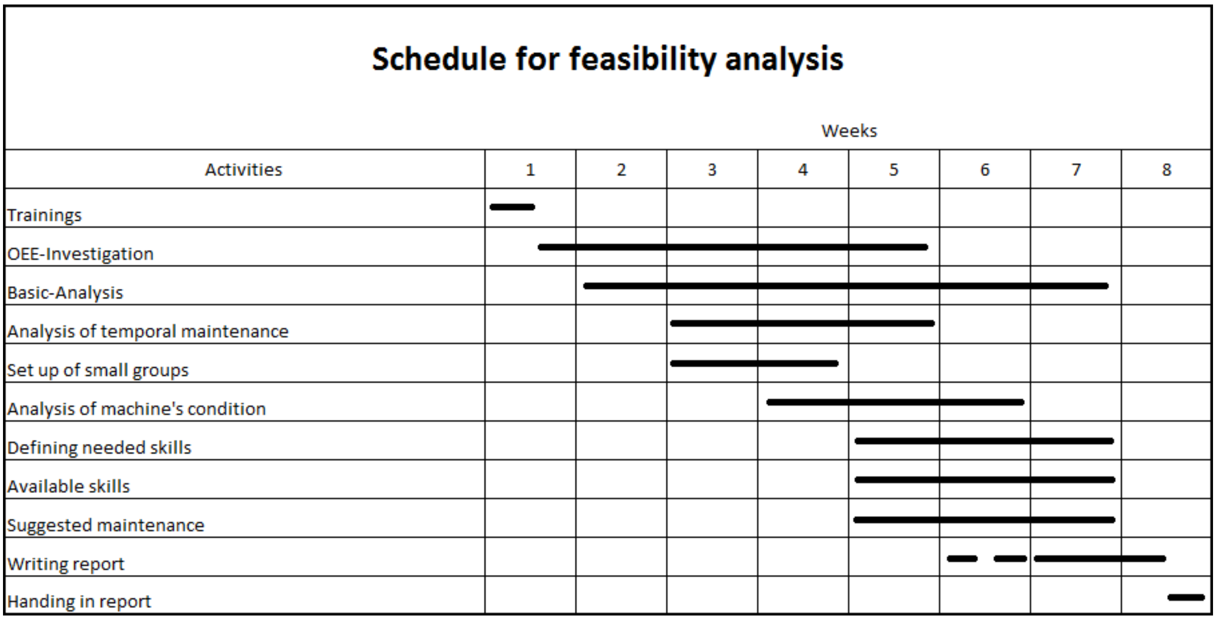


Figure 18: Schedule for feasibility analysis[112]

3.4 Maintenance Outsourcing

Maintenance is crucial for the performance of a company. A lot of companies and especially SMEs do not recognise or have the capability for effective maintenance which results in a competitive disadvantage. Weissenbach claims that medium companies have limited resources for maintenance. As machines and equipment are getting more complex, there is a challenge to maintain a certain level of knowledge with the employees so to fulfil the maintenance tasks. While medium companies are still able to provide proper maintenance, small enterprises do not have an organisational structure for maintenance due to a lack of employees and knowledge. A solution for this can be a corporate maintenance. In general, it is a corporation between the manufacturer and the maintenance service provider. A case study in 2016 showed that there is more opportunity than risks persisting in corporate maintenance

[112] (Hartmann, 1998)

models. The highest potential is given in the technical and economic part. According to simulations, the maintenance costs were reduced by 23,3% and the breakdown time by 15,2%. Further simulations show that there is even higher potential, depending on the size and parameters of the companies. On average, there is a total cost reduction of 37,3% and a reduction of maintenance cost of 58,5%. The breakdown time can be reduced by 4,2% generally and the availability is increased by 0,6%[113]. Already in 2009, Horn indicated the potential of maintenance outsourcing. His study demonstrated that successful outsourcing reduced the costs of 15 % in average and in some cases even by 30%[114].

Besides the case study and the simulation of A. Weissenbach, another case study was conducted in 2015 in Saudi Arabia which was measuring and comparing the benefits of outsourcing manufacturing to service providers. It can be concluded that outsourcing of maintenance services is beneficial and plays an important role for the company's success. Especially for maintenance tasks that have a low frequency and a high need for skills, knowledge or equipment, it is necessary to outsource them. Meanwhile, the occupation of operation should not be outsourced. In general outsourcing should lead to cost saving and better service execution and quality. Therefore, it is necessary to determine the costs and the actual state of maintenance costs as well as malfunctions[115].

Back in 1995, a survey among the companies in North America lead to the result,that 35% of the companies considered outsourcing for at least part of their maintenance activities. In case the machine or product is very specialised, the maintenance and spare part replacement needs to be obtained by the original equipment manufacturer (OEM)[116].

3.4.1 Scenarios for Maintenance Outsourcing

Maintenance of a system or product consists of three main activities. Which of these can be outsourced depends on the scenario.

- The work planning - Which components need to be maintained?
- The work scheduling - When is it necessary to carry out the maintenance?
- The work execution - How to carry out the maintenance?

In the first scenario, the work execution is completed by the service company, while the work planning and scheduling is still the task of the customer. The next scenario

[113] (Weissenbach, 2016)
[114] (Horn, 2009)
[115] (Al-Mutairi, 2015)
[116] (Campbell, 2006)

possibility is, that the customer is neither designing the schedule nor doing the work execution. The customer in this scenario is only responsible for the work planning, whereas the service agent carries out the remaining two tasks. The last scenario is comparable to a complete outsourcing of the maintenance activities, since the service agent is responsible for all activities. The possibilities are shown in figure 19[117].

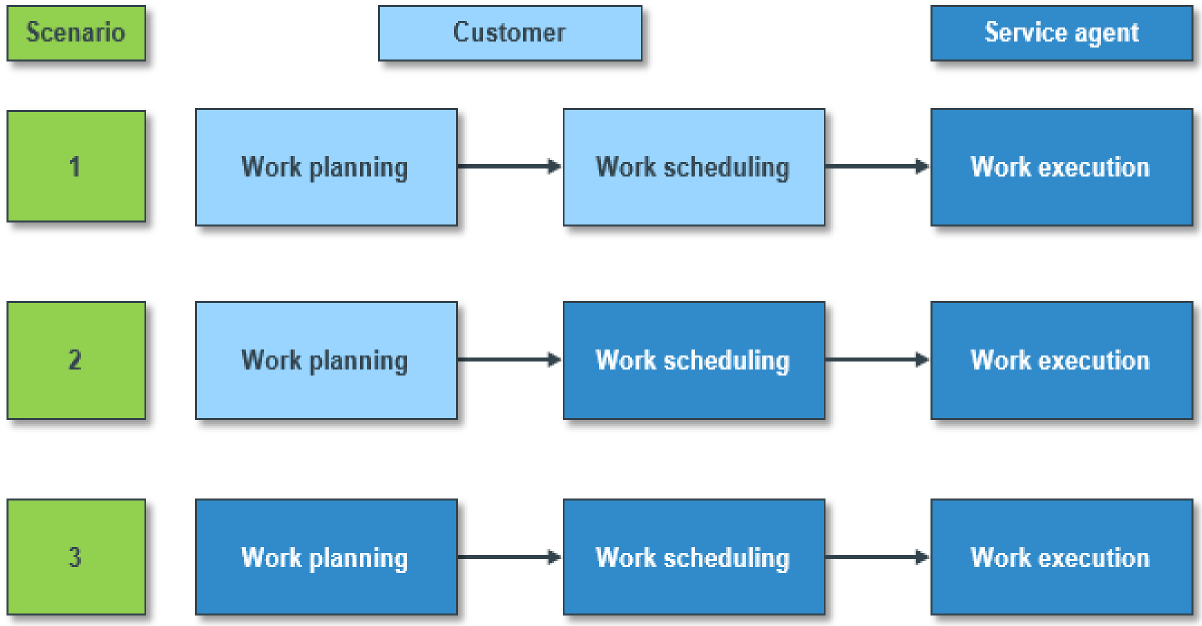


Figure 19: Different maintenance outsourcing scenarios[118] (modified figure)

3.4.2 Maintenance outsourcing process

The maintenance of equipment is already a complex process. This process becomes even more sophisticated, as soon as maintenance is outsourced. It involves two parties now, the customer and the service agent. The responsibility for each maintenance task can be on one of these parties, depending on the defined elements in the maintenance service contract[118]. A complete outsourcing of maintenance activities is more relevant for SMEs, whereas big companies tend to outsource subareas or subprocesses. However, the method is the same and varies only in scope and, is clustered into three stages[119].

Stage 1 (duration approximately 2-3 months) – **[Pre-purchase]**

Outsourcing is a fundamental decision and requires clearly defined objectives and reasons. The framework for the outsourcing element needs definitions concerning employees, materials and equipment. To identify the relevant information the employees have to be included into this process and afterwards, three to four possible maintenance service partners can be chosen. These partners evaluate the potential

[118] (Murthy, Jack, 2014)
[119] (Horn, 2009)

and develop concepts from which the customer has to select[119]. The main part of this stage is to search for information concerning the different service providers and details of maintenance contracts, which can be standardised or customised depending on the equipment[118].

Stage 2 (duration approximately 6-7 months) – **[Purchase]**

Contract options are evaluated and details concerning terms, exclusions, period etc. are defined[120]. The processes within the project require more detailed planning which incorporating short, middle and long-term actions. Furthermore, it includes the responsibility and the information system, the offices, the system, the affordable budget and the common objectives. Before the service contract is extended to the whole plant or subareas, a pilot project needs to be conducted[121].

Stage 3 (duration approximately 6 months) **[Post-purchase]**

The service agent takes the whole responsibility for the promised services now. The agency optimises the organisation, methods and strategy. Furthermore, there is constant communication, fixed appointments, adjustments and the extension or renewal of the maintenance service contract[121]. As the asset's performance depends on the maintenance of the provider, the performance of maintenance service should be monitored by the customer. However, the service provider needs data as well and should ensure a constant flow of information concerning usage, speed and performance[120].

3.4.3 Maintenance Service Contract[122]

The maintenance service contract (MSC) is a written agreement, that creates obligations between the customer and the OEM and deals with several issues:

- Technical issues: The trend is growing for functional guarantee contracts. This contract helps to predict the output of a machine. For example, it binds the service agency to a special amount of electricity produced by a power plant. It is important to consider special restrictions in the contract like: usage intensity or operating conditions.

- Economic issues: The parties have to agree on a contract payment structure. A few examples are: variable price, fixed price, cost plus incentive fee, cost plus margin, cost plus fixed fee, cost plus award fee or a price ceiling incentive.

[120] (Murthy, Jack, 2014)
[121] (Horn, 2009)
[122] (Murthy, Jack, 2014)

- Requirements: Each party might have some special requirements that need to be considered. For example, the customer not being able to extend the usage intensity, while the service agent needs data to determine and plan service appointments.

- Contract duration: Usually this part is determined with an option to extend or a renewal at the contract's end.

- Moral hazard: Cheating of the parties need to be addressed. It can occur when the service agent is doing the maintenance below the nominated maintenance and the customer cannot prove it. Cheating by the customer would be if the usage is higher than the agreed one.

- Dispute resolution: This part defines the steps if there is a dispute between the two parties. For example, a solution would be to go to a third party that is able to resolve the problem.

Murthy and Jack collected the key elements of a maintenance service contract. Those key elements are shown in table 4. If the contract is missing some of these elements the long-term costs might increase.

Table 3: Key elements of MSC (modified table) [123]

Parties involved	SA supplier of service and customer (recipient of the service), their names and addresses, etc.
Definitions	glossary of frequently occurring words in the document
Description of the service	maintenance actions, materials, labour, etc.
Performance levels	
Delivery of the service	single or multi locations
Term	start date and period of agreement
Pricing details	these can vary considerably from contract to contract
Pricing adjustment	e.g. annual increases linked to inflation or some other index
Payment details	annual, monthly, after each service, etc.
Responsibilities of the SA	details of services to be performed and SLAs if applicable
Responsibilities of the customer	usage of product or system
Indemnification and insurance	
Bankruptcy	
Confidentiality	
Termination	
Renegotiation/renewal	

3.4.3.1 The maintenance Service Contract process[123]

The main elements and interactions of the maintenance service contract process are shown in figure 20. As a maintenance service contract is regulated by different issues, the framework for the contract can be more stable or flexible, depending on the contract payment structure. The shown structure in the figure is an example for a more complex one. The following elements shall be described briefly:

<u>Owner</u> – a business or agency that has to take into account the interests of stakeholders

<u>Asset state</u> – the current condition of the asset

<u>Initial state of asset</u> – the initial state of asset describes the usage, maintenance and failures of an asset. If the owner does not know the whole history about it, the state of

[123] (Murthy, Jack, 2014, p. 111 - 112)

the asset is uncertain. The owner is able to reveal the whole information or hide some information about the state.

Usage of asset – a more complex system is able to describe the asset production rate. This means, that the usage depends on the quantity of produced goods by the asset.

MSC – the maintenance service contract varies from few years to ten years and is a complex and customised element.

MS Providers – the number of maintenance service agents varies and depends on the branch. The more specialised a machine is, the less is the number of maintenance service providers. The competency is an important subject for the customer.

Selection process – The selection of providers depends on the branch. In general there is a public call for service agents and through different offers the best fitting can be chosen. Factors like cost, competence, reputation and risks influence the decision.

MSC costs – the costs depend on the point of view. On the one hand we have the owner of the asset and on the other hand there is the service provider.

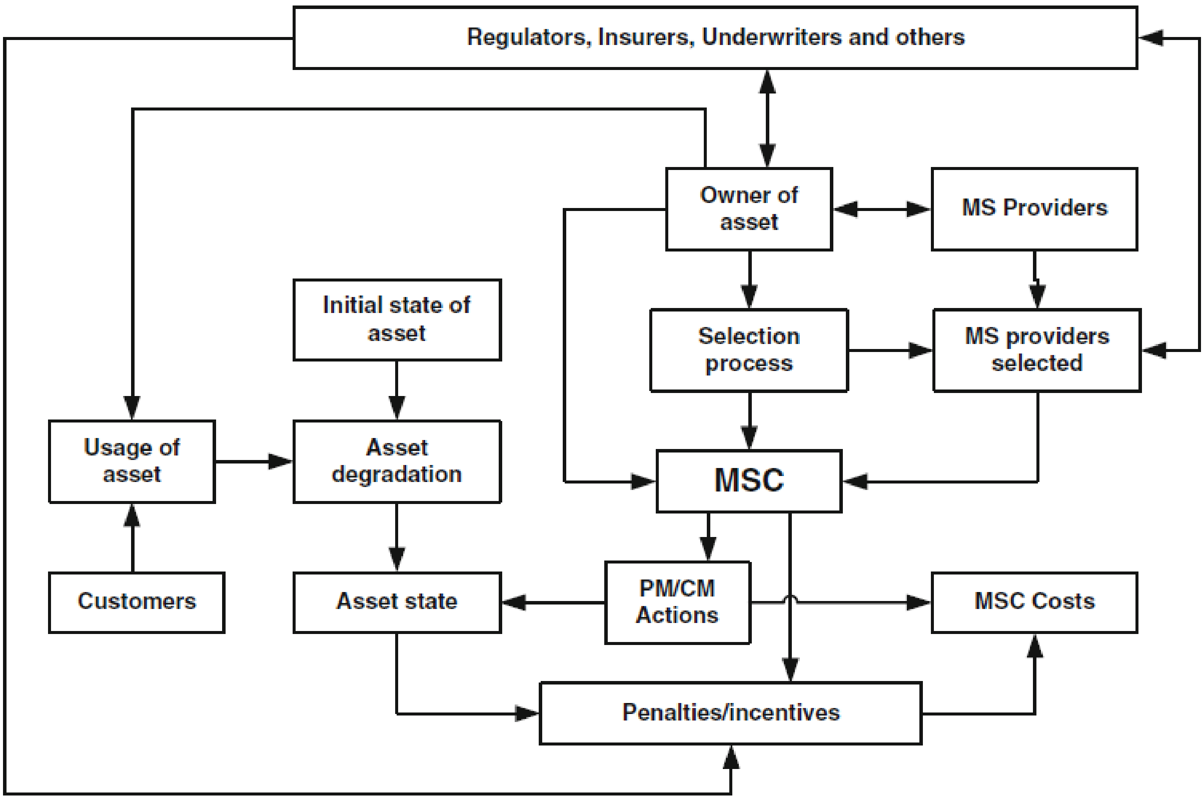


Figure 20: MSC process for complex systems[124] (modified figure)

[124] (Murthy, Jack, 2014)

3.4.3.2 Types of Maintenance Service Contracts

There are three different types of maintenance service contracts available. The work package contract, the performance contract and the facilitator contract. Those contracts differ in complexity, duration and amount of knowledge[125]. A better overview of the three possibilities is given in figure 21.

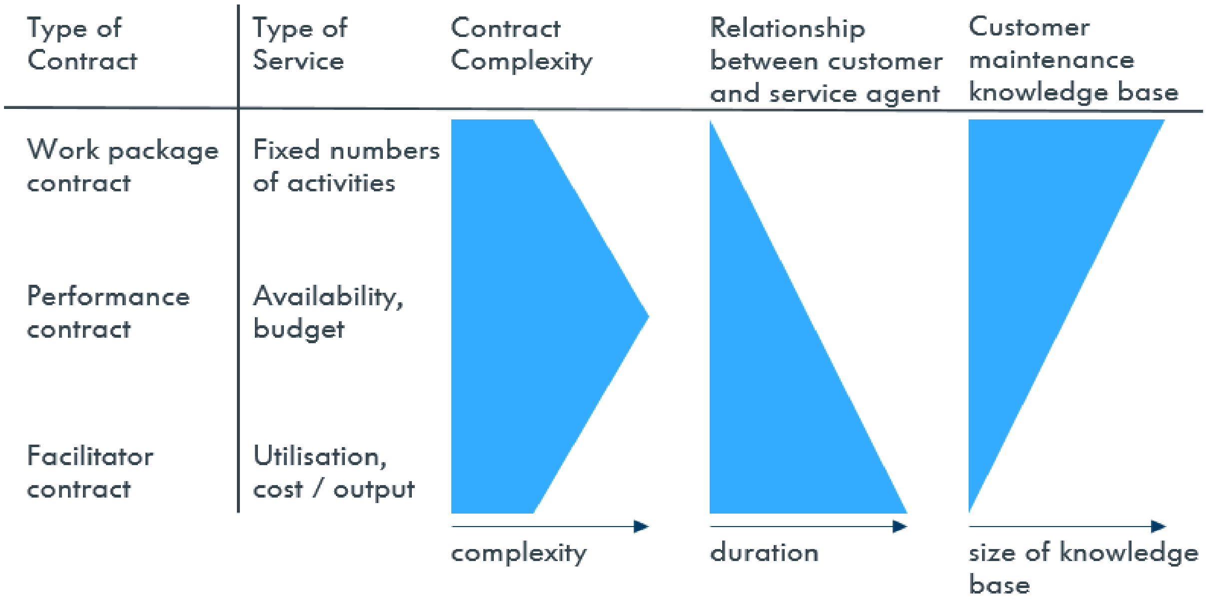


Figure 21: Basic types of maintenance concepts[125] (modified figure)

Work package contract

The work package contract is the basic type of contract. The whole responsibility and knowledge is kept to the customer. The customer plans the maintenance activities, takes care of spare parts and does maintenance requests according to their production. There is no need for a close obligation between the client and service agent, since the knowledge remains the manufacturer's.

Performance contract

The performance contract aims on the performance of the client. The service agent guarantees a certain overall equipment availability. As the performance depends on many influences and interactions, the complexity of this type of contract may be large. It requires a good technical knowledge of the equipment to identify the interacting parameters. Both parties have to agree on a defined performance level before the contract gets valid. As the influences and parameters take some time to analyze, the process of a contract can be time intense. This leads to the fact that this type of contracts is only beneficial if the customer and the service agency intend to work for a long-term periode together.

[125] (Martin, 1997)

Faciliator contract

This facilitator contract describes the customer more or less as a user. The service agent is owner and maintainer of the equipment and the customer is only paying for the use. The complexity in this contract is less than the performance contract, as all responsibilities belong to the service company. The benefit for the customer is that the company is highly flexible with the investment[126].

However, maintenance contracts like this give no incentive to the service agent to improve the performance. For this Tarakci et al. described a new type of contract, the so called incentive contract. The benefit of this type of contract is that it leads to a win-win situation for both parties. This is attained by bonus payments for less maintenance times or less failure rates. The disadvantage is that this type of contract requires a lot of information concerning the maintenance design, activities and breakdowns. Also the time for planned maintenance and corrective maintenance for a service agent my vary from the collected data. Another aspect is that some information might be asymmetric and proprietary, so that the other party has no access to this information[127].

3.4.3.3 Maintenance Service Contract Costs

Maintenance Service Contract costs are dependant on the point of view of each party. The period of maintenance actions and the payment made by the customer are defined in the contract. Depending on the contract's structure, costs preventive maintenance are executed by the service provider or by both parties. Not all maintenance services, also not the maintenance costs can be predicted. There are two types of service costs - cost per unit of sale or the cost per unit of time. To estimate the relevant costs a proper framework is needed for an optimised decision making process by the service agent and the customer.

Costs can be separated into basic costs for services that deal with corrective maintenance and service costs that deal with preventive maintenance. Key elements for each cost type are costs for maintenance actions, material or spare parts, labour costs as well as transport costs.

Cost per unit sale

The costs per unit sale are the service costs for providing a single service. Depending on the service and the claim the costs can vary. The modelling of this cost depends on elements which are under the control of the customer and the service provider. The process is regulated on the key elements and shown in figure 22.

[126] (Martin, 1997)
[127] (Tarakci, Tang, Moskowitz, Plante., 2006)
[128] (Murthy, Jack, 2014)

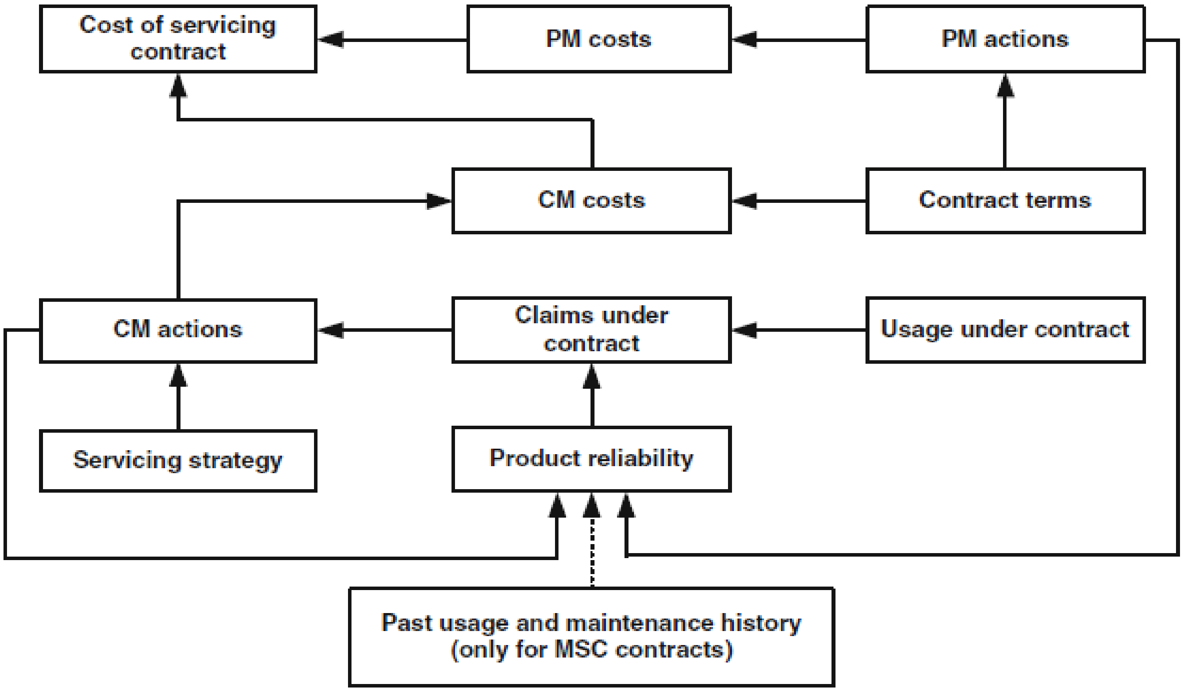


Figure 22: Elements for cost per unit sale[128]

Cost per unit time

Costs per unit of time considers the costs for a time period. The pricing is achieved by the aggregation of servicing costs over time, to estimate the costs per unit of time. Derived from past experiences the service provider and customer are able to determine the estimated costs for the contract. This process is shown in figure 23[129].

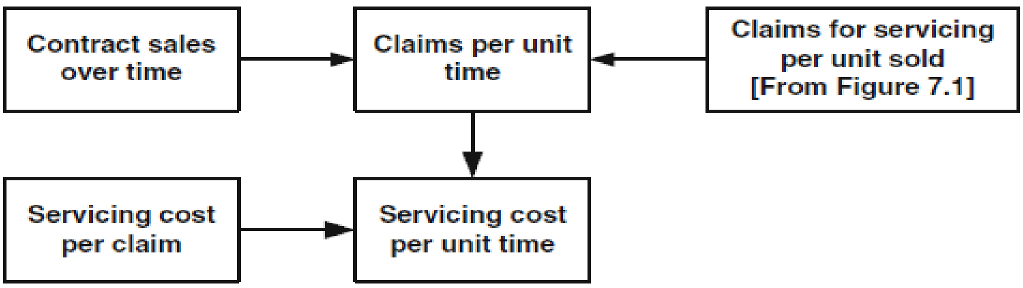


Figure 23: Elements for cost per unit time [129]

3.4.4 Maintenance Outsourcing Concepts

There are different maintenance and product support designs to find in literature. Depending on the demands and the approach each concept has its own benefits, depending on the demands. One approach by Horn aims to improve the maintenance actitivies. While another approach by Markeset and Kumar aims to reduce maintenance activities through an improvement of the product design.

[129] (Murthy, Jack, 2014)

3.4.4.1 Proactive Maintenance

In 2009, Horn developed together with 'Piegenbrock Instandhaltung' a maintenance outsourcing concept for SMEs called proactive maintenance. The developed 'concept' focuses on the following aspects:

- Maintenance is the core competence of the maintainer
- Act is more important than react
- Ensure an efficient and sustainable maintenance, based on long-term concepts
- Continuous communication and information as success factor
- Documentation of costs and activities
- Merging all relevant data (machine, operation, quality, inspection etc.) in a maintenance tool –preferable PIHDAS (Piepenbrock Instandhaltungs-Daten-Analyse-System) and for the interfaces SAP-PM
- Classify the equipment, machines and tools according to their importance in the value added chain
- Order the classified equipment, machines and tools in uphold classes
- Implement a KPI measurement system, based on VDI 2893
- Set up different maintenance strategies with different service levels (figure 24)
- Set up bases with maintenance employees nearby the customer
- Integration of work security, quality and environment management
- A continuous improvement process (figure 25)[130]

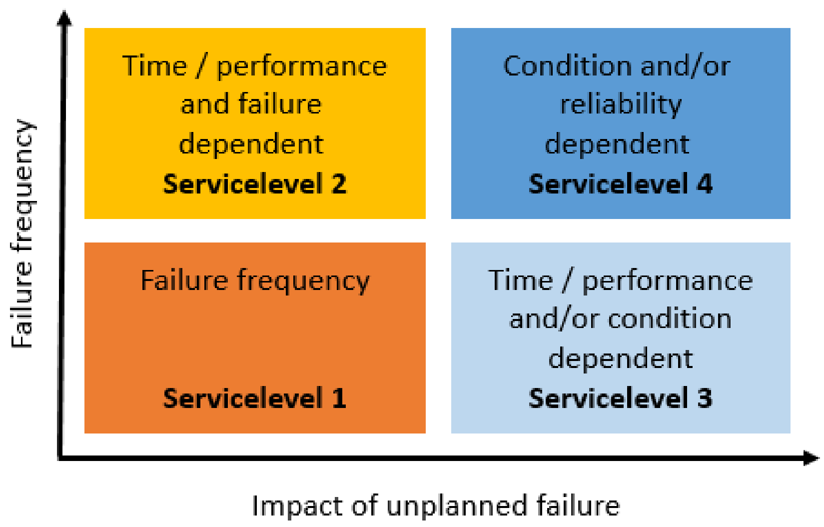


Figure 24: Service Levels[130] (modified figure)

[130] (Horn, 2009)

Figure 25: Continous improvement in maintenance service[131] (modified figure)

3.4.4.2 Design for maintenance and product support[132]

Whilst most of the above shown concepts focuses on improving maintenance activities through planning, the approach of the researcher Markeset and Kumar aims to reduce the need for maintenance activities and product support through product design. According to Markeset and Kumar there are two options for a company. Either the maintenance activities are designed out or the OEM is trying to optimize the design of the equipment with respect to maintenance activities.

The methodology of the concept is an action research methodology in which the researcher collects data by participating in the operating process. The data collection is done through surveys, interviews, conversations, participation in meetings and company literature analysis. As customers aim to increase the reliability and reduce the costs of the equipment, the life-cycle costs analysis is being used to identify potential improvements. The life-cycle costs analysis helps to identify erros in the

131 (Waeyenbergh, Pintelon, 2004)
132 (Markeset, Kumar, 2003)

production process and derives root causes of product support and maintenance requirements. Derived from this data is the maintainability which helps to analyse if there is a design available. By answering questions like: Is the origin of the problem easy to maintain or easy to access? Further, product support and spare part logistics are being considered. The whole process is shown in figure 26.

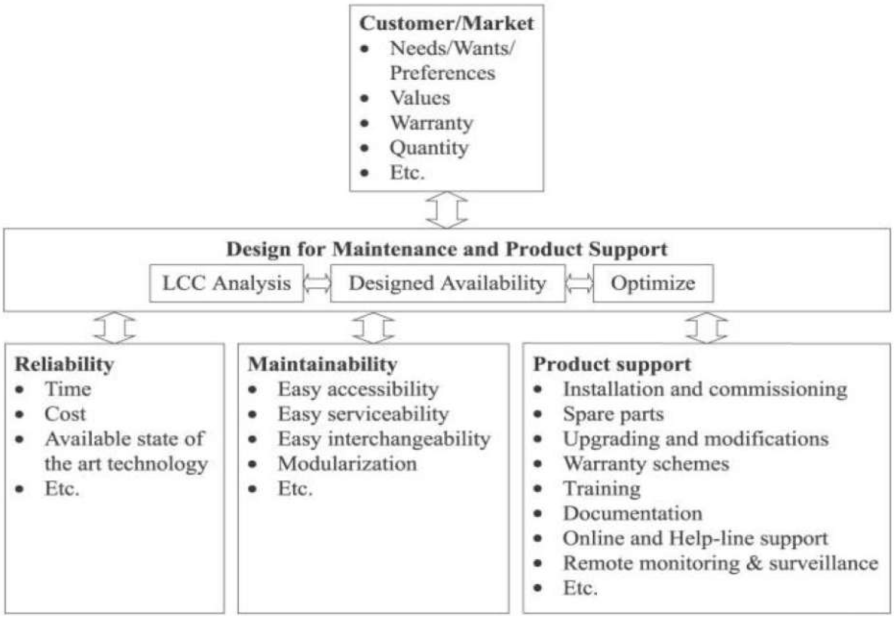


Figure 26: Design for maintenance and product support[133]

3.5 Framework for maintenance concept[134]

A framework for maintenance concept development specifies the steps needed to determine a roadmap for effective and efficient maintenance. It matches the requirements, mentioned in chapter 3.4.1 Scenarios for Maintenance Outsourcing concerning the two steps of work planning (which components need to be maintained and work scheduling (when is it necessary to carry out the maintenance). In the previous chapter different maintenance concepts have been introduced. These concepts are often valid for a special kind of equipment or branch and are time consuming to implement. Waeyenberg and Pintelton investigated the different concepts and established a framework that considers factors which describe the system, the interrelations and the organisational structure. These factors need to be addressed to reach the full potential of a maintenance concept. However, the most important is the last of the activities, the work execution (how to carry out the maintenance). Besides the importance of the different factors, the fast changing industry makes it necessary to review the maintenance concept periodically, to be able to consider demands, needs and chances in the rapidly evolving environment.

133 (Markeset, Kumar, 2003)
134 (Waeyenbergh, Pintelon, Gelders, 2001)

Taking these requirements into account, the framework for maintenance concept development is based on the developed concept by the Centre for Industrial Management (CIB). The framework consists of seven modules and is shown in figure 27.

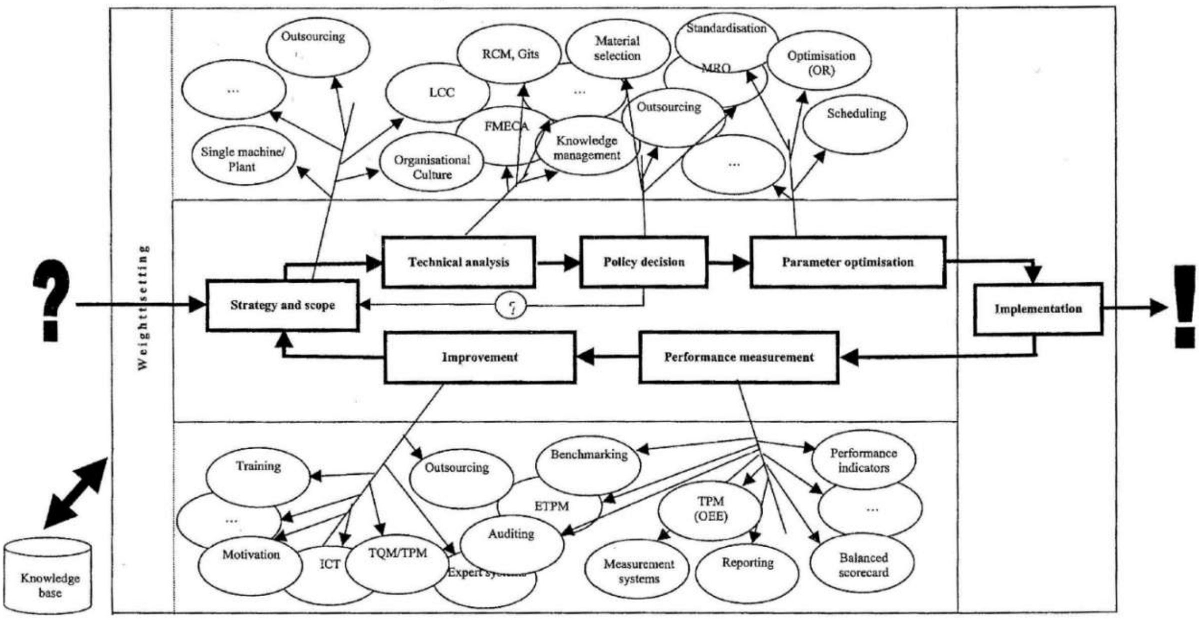


Figure 27: Framework for maintenance concept development[135]

3.5.1 Strategy and scope[135]

This module consists of long-term decisions that are in line with the company's strategy. Besides maintenance aspects, other issues like capacity, flexibility, economic factors and investment should be further considered. Therefore, it is important to cooperate with different departments in this section (Human Resource, Top Management, Accounting, Production, Maintenance, Engineering).

The following tasks should be carried out:

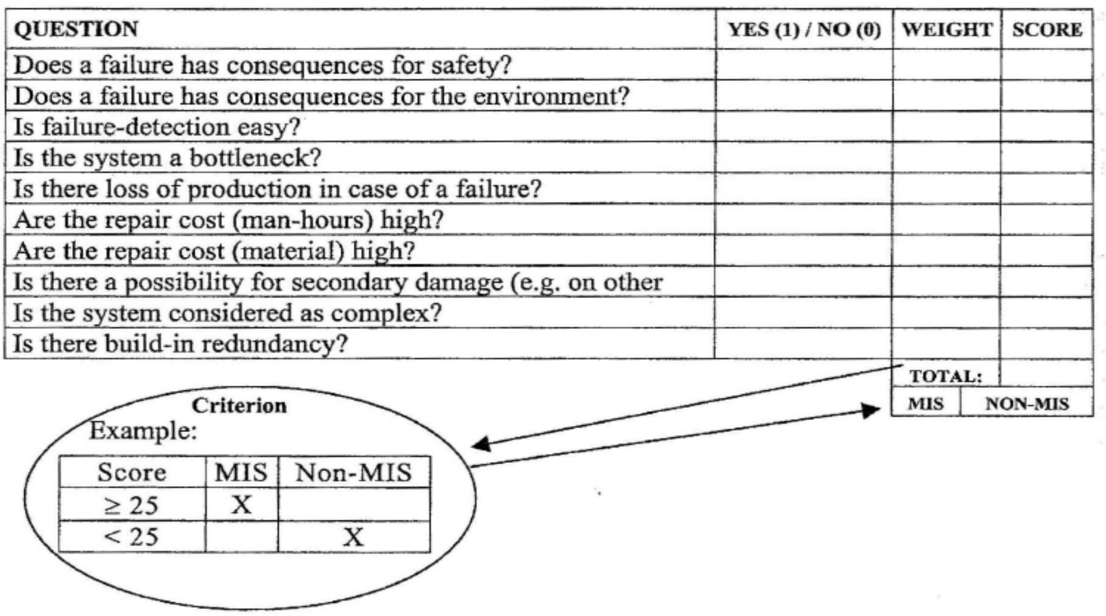
- Evaluation of current culture and situation
- Defining the ideal situation (objectives)
- Identify performance parameters
- Task assignment and team formation

Similarly to other operating functions, maintenance needs objectives as well, that must fit to the company's objectives.

135 (Waeyenbergh, Pintelon, Gelders, 2001)

3.5.2 Technical analysis[136]

The technical analysis contains the data collection. This module ensures the optimal available means of production. For this, distinctions between the data are made. It differs between first and second level data. First level data is recorded during the system installation, while second level data is collected during the normal work process. In particular, the second level data is important for ensuring continuous improvement. However, the general technical analysis process is top-down and consists of two preliminary identifications. First of all, the most important system is to be identified. The aim being to reduce system complexity. For this, a questionnaire helps to analyse the most important system. The questionnaire can be seen in the figure 28. Depending on the importance on each factor a weight factor can be included into the questionnaire. This makes the identification of the most important system more flexible.



QUESTION	YES (1) / NO (0)	WEIGHT	SCORE
Does a failure has consequences for safety?			
Does a failure has consequences for the environment?			
Is failure-detection easy?			
Is the system a bottleneck?			
Is there loss of production in case of a failure?			
Are the repair cost (man-hours) high?			
Are the repair cost (material) high?			
Is there a possibility for secondary damage (e.g. on other			
Is the system considered as complex?			
Is there build-in redundancy?			
		TOTAL:	
		MIS	NON-MIS

Criterion

Example:

Score	MIS	Non-MIS
≥ 25	X	
< 25		X

Figure 28: Questionnaire to identify the most important system[136]

After establishing up the most important system, the most critical components within the most significant system can be identified through the FMECA and the following activities.

- Failure mode - recognise & evaluate potential failure of the system or the process and its effects
- Failure effect - identify actions to eliminate potential failure that could occur
- Failure criticality – examine potential failure of the service, product or process and how critical the failure would be.

[136] (Waeyenbergh, Pintelon, Gelders, 2001)

3.5.3 Policy decision[137]

The policy decision can be made with a decision tree. It helps to find the correct maintenance policy for each component by answering the question positively or negatively. As soon as a policy is technical possible the question to whether it is economical arises. If none of the possibilities seems to be beneficial, a review of the criteria and data is possible or outsourcing can be considered. The decision making tree can be seen in figure 29.

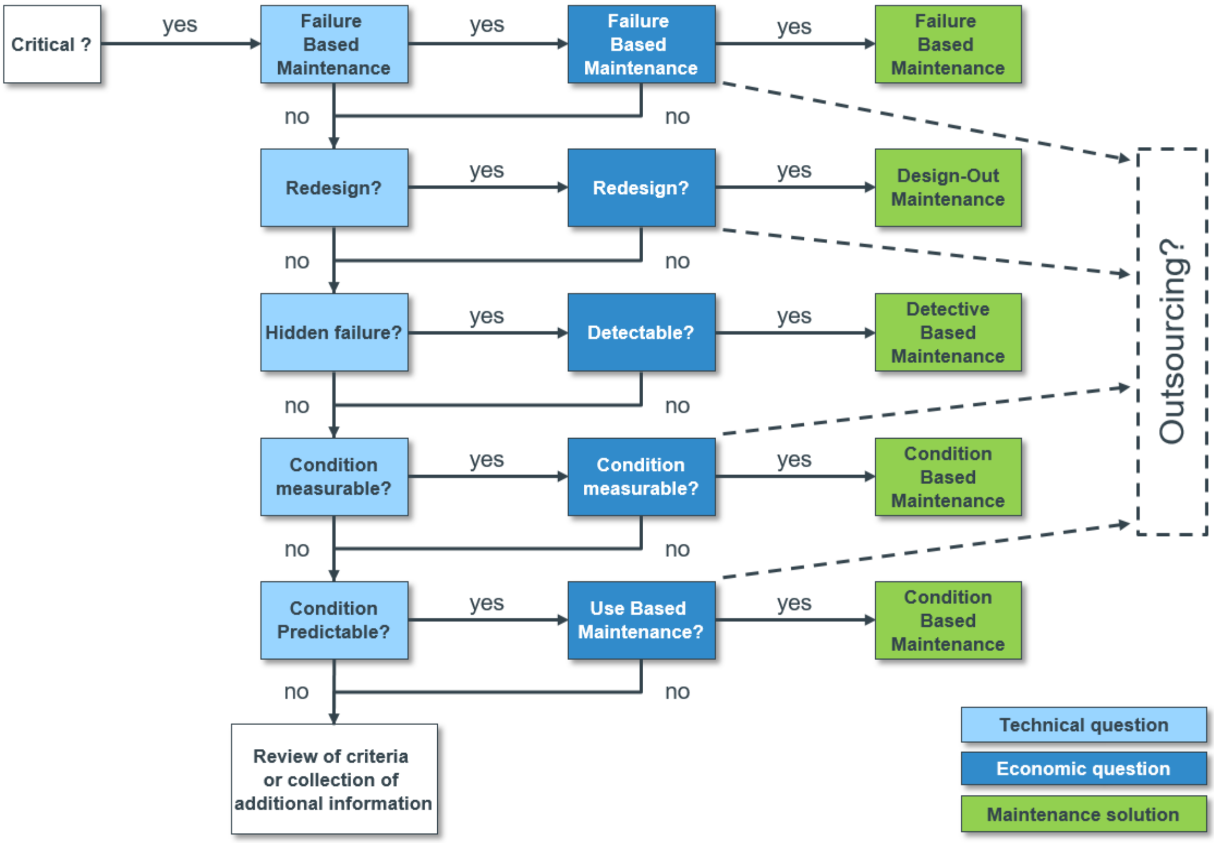


Figure 29: Maintenance policy decision tree[137] (modified figure)

3.5.4 Parameter optimisation[138]

As soon as the policy is known, their parameters need to be optimized[135]. For the time-based maintenance policy and the conditionbased maintenance policy there are two approaches for each. An overview is given in figure 30.

[137] (Waeyenbergh, Pintelon, Gelders, 2001)
[138] (De Jong, 2017)

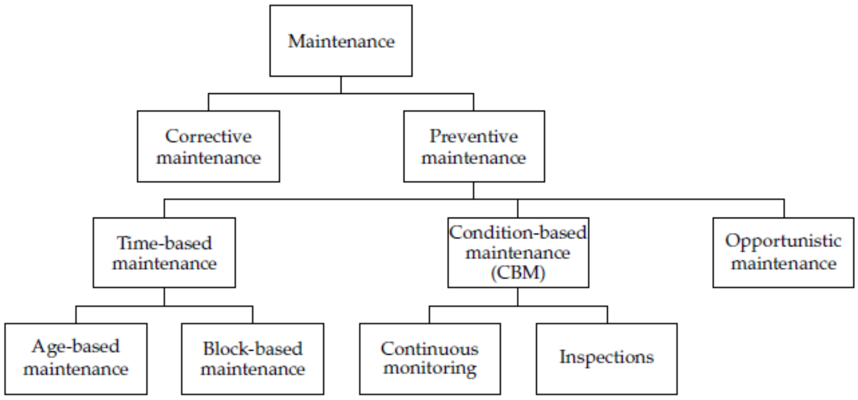


Figure 30: Schematic overview of maintenance policies[139]

The advantage of time-based maintenance is its simple implementation as it only considers the time a part is in the service. However, if a part or unit is still in good condition, precious useful remaining life is wasted when the part or the unit is changed and maintenance performed. The challenge with condition based maintenance is that it is only possible when there are conditions that can be measured or monitored. Depending on the frequency of the condition being monitored there can be two methods distinguished in terms of the condition based maintenance. It can be either performed continuously or periodically by inspections. The disadvantage of continuous maintenance is, that it is often expensive and requires special devices, whereas periodically inspections might miss deteriorations in between the inspections.

For time-based maintenance there is either the possibility of age-based or block-based maintenance available. Time-based maintenance describes a maintenance service as soon as the unit or part reaches a prescribed maintenance age T or if the part fails, corrective maintenance is performed. The block-based approach makes use of maintenance intervals that have to be performed after determined time intervals T. Similar to the time-based maintenance, block-based maintenance utilises corrective maintenance as well as soon as a unit breaks. Figure 31 helps to get an overview of the time based maintenance approaches[139].

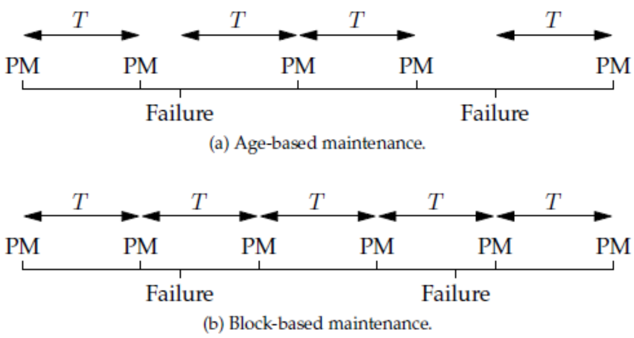


Figure 31: Time-based maintenance approaches[139]

[139] (De Jong, 2017)

3.5.5 Implementation[140]

The implementation describes the necessary actions for the placement of the maintenance activities. Since the maintenance concept development within this study is merely used for the concept development and not for the implementation, the implementation will be discussed further in chapter 4.2: Implementation and Organisation of TPM.

3.5.6 Performance measurement[140]

The measurement of maintenance performance is challenging. On the one hand the maintenance activities are dependant on production activities, whilst on the other hand there is a time delay. Systems that measure the performance of a system rely on performance numbers or indicators. These indicators measure a specific aspect which is related to the performance.

As mentioned in chapter 3.1.1: Performance Measurement System, the performance measurement and its key performance indicators are highly dependent on the company's strategy and should be derived from the company's goals.

3.5.7 Improvement[141]

For the successful realisation of maintenance and outsourced maintenance, it is necessary to provide continuous, honest and cooperative communication between the customer and service agent. Deviations in terms of performance or goal attainment need to be discussed in good time in order to allow for adjustments and actions. Especially the definition of common goals is essential for success.

140 (Waeyenbergh, Pintelon, Gelders, 2001)
141 (Horn, 2009)

4 Methodological approach to develop the maintenance concept for SME

As there are different outsourcing scenarios available, it is mandatory to cluster different activities with various methods. The aim is to develop a service provided maintenance concept for SMEs that includes all three mentioned main activities.

- The work planning - Which components need to be maintained
- The work scheduling - When is it necessary to carry out the maintenance
- The work execution - How to carry out the maintenance

Besides the main activities the following questions have to be faced to be able to generate a service provided maintenance concept for SMEs:

- **Q1:** How to set up a maintenance concept?
- **Q2:** How to implement and organise the maintenance concept?
- **Q3:** How to measure the performance of the maintenance concept?

For this, the above-mentioned concept by Horn shall be investigated according to the demands. Afterwards the framework for maintenance concepts by Waeyenbergh / Pintelon will be introduced, which covers the demands to the work planning and scheduling. The design of work execution and the arising question how to carry out the maintenance will be handled by the TPM concept as well as its feasibility analysis and implementation. Before the methods of data analysis and collection are described, the used tools, Ishikawa diagram and the OEE – key performance indicator – will be further introduced.

4.1 Existing concept for maintenance outsourcing

The above mentioned concept from Horn has been investigated and the demands, depending on the research question and the goals were applied to it. The comparison of demands and the already existing concept are illustrated in table 5. Derived from this, a new concept has to be developed that extends the possibilities.

Table 4: Comparison of concepts (own depiction)

Task	Pro active Maintenance	Design for maintenance	New Concept
Outsourcing scenarios	-	-	+
Work planning	+	-	+
Work scheduling	+	-	+
Work execution	+	-	+
Maintenance Concept	-	-	+
Maintenance Strategy	+	-	+
Implementation	-	-	+
Causes and Effect	-	+	+
Possible Solution	-	+	+
Part redesign	-	+	+
Performance measurement	+	-	+
Continuous Improvement Process according EN	+	-	+
Short-term increasing of efficiency	-	-	+
Long-term increasing of effectiveness	+	+	+

4.2 Implementation and Organisation of TPM

To answer the question of 'how to carry out maintenance and do work execution' the concept of implementing and organising TPM into a company needs to be considered. To ensure a successful implementation , certain steps are needed to guarantee a successful last step in the maintenance outsourcing.

The implementation of TPM consists of three different stages:

- Planning and preparation of the installation of TPM
- Pilot installation of TPM
- Plant-wide installation of TPM

4.2.1 Planning and preparation of the installation of TPM

Planning the installation of TPM will help to ensure a simple installation of TPM. The better the feasibility analysis has been accomplished, the faster this stage can be completed. There are similarities between the feasibility analysis and the first stage of the implementation of TPM. In general, it is clustered into ten steps:

1. Develop an installation strategy

The analysis of the company's culture, the skills and the requirements help to order the actions for the TPM implementation. Hartmann suggests an order of TPM-EM, TPM-PM and finally TPM-AM. According to his experience, this order works best in most of the already existing companies. Although this order is not fixed, as it depends on the company and its condition.

The benefit of optimising the TPM-EM first is, that it leads to quick success. The increasing performance can assist in showing the benefit of TPM and helps the implementation of other steps. Whereas in existing companies it is advised to start with TPM-EM, it can be easier for a new company or for example a Japanese one to start with TPM-AM.

Besides the order of each installation, priorities need to be identified as well. It can be easier to implement TPM in one area of the company that another. Depending on the needs of the production and equipment focusing on bottleneck machines can support to increase the productivity of the whole plant. Another priority might be concerning the motivation of some employees. A department with high motivation to implement TPM should be preferred to start, instead of a demotivated one.

2. Developing and implementing a TPM organisation structure

If a company decides to realise TPM, it should name a responsible employee – for instance the TPM manager - who reports to the TPM champion and coordinates the TPM in the organisation. Typically, it is an engineer or an employee with experience in maintenance. The so called 'TPM champion' is generally in a position of leadership and is responsible for the whole production process or the whole maintenance within the company. He is also responsible for the leading and direction of TPM and reports to top management. If the company is too big to report directly to the management, there should be a TPM committee that involves the managing director, production manager, plant manager, head of personnel, head of maintenance, the TPM champion and the TPM manager.

As soon as the decision was made to implement TPM, there is a need for a TPM board. This board will help the manager in TPM trainings and planning. Employees who assisted the feasibility analysis can be considered for this task, although it is not necessary. Furthermore, there should be a definition of every single position and its tasks. For this, a new hierarchical structure should be established.

The implementation of the above-mentioned groups of employees, who ensure a continuous improvement, must be set up. Depending on the size of the company, there could be another hierarchical level between the board and work groups organised. This TPM division board would consist of division leaders and maintenance leaders, the TPM manager (or another board member), an engineer and a representative or the maintenance and the operating employees. Although the organisational structure is more complex, it will help to implement the TPM later as the responsibilities are determined and the participants know who is their contact person and who supports them in case of needs.

3. Develop a TPM vision, strategy and policy

Before going public with the idea of TPM, the vision, strategy and policy needs to be defined. The TPM committee is responsible for describing the vision that takes a long-term perspective of five to ten years. The vision is based on the feasibility analysis and helps to define the promising future of TPM. The next step is the definition of the TPM strategy to ensure the vision can be reached within one day. The strategy considers the company's strategic goals for the production, costs and quality as well. The policy of TPM is necessary to be transparent to the employees. As most of the employees will have never heard of this kind of concept they will come up with different questions. Questions like: Will we earn more money? Will I be able to complete the maintenance at my machine by myself? How much time do we have to spend for TPM? and many more. Before communicating to the employees about TPM, these questions should be already answered.

4. Develop the goals of TPM

The goals of TPM can be build up on the feasibility analysis. An elementary way to establish goals is to take the temporal OEE and aim for an OEE that is approximately 85% or the current OEE can be taken and improve it accordingly. Depending on other influences it is further possible to improve the TEEP, the quality or alternatively reduce scrap, idling or break downs[142].

Examples for goals of the top management could be:

- Reduction of total cost by 10%
- Reduction of production cost by 5%
- Increasing of added value per person by 10%
- Reducing lager capacity by 15%
- Reducing the number of customer complaints to 5 per customer

[142] (Hartmann, 1998)

Examples for goals of the middle management could be:

- Increasing working productivity by 10%
- Increasing the OEE from 50% to 65%
- Increasing the output per hour to 1.000 pieces
- Increasing the number of suggestions for improvements from 5 to 10 per employee
- Reducing the number of accidents to zero[143]

5. Trainings for TPM

There are three different types of training that need to be considered. The first one is the training of the management for TPM. For this, it is common to have an external consultant who is an expert in TPM and teaches the management about its benefits. The next training would be to inform and train the employees in TPM. It includes a description, the set up and the influences of TPM.

6. Perform PR

The next step would be to realise TPM more public and publishing the idea of TPM in the company. Depending on the size of the firm, it could be published on its intranet, in the work newsletter or also at weekly meetings. Other options would be posters or black boards.
This stage is of significant importance as it helps to motivate and enthuse the employees for TPM.

7. Develop a whole plan for TPM

The plan is generally prepared by the TPM manager and his board. The idea involves getting an overview of the TPM activities that are needed to reach the envisaged goals. The first part would be to define the chronology of the implementation of TPM-AM, TPM-EM, TPM-PM, how much time it takes and where in the company it will be implemented first. It is not possible to organise all of this without any practical experience of TPM. It helps to get an overview of all the tasks that have to be accomplished until TPM is implemented within the whole company. After the first installation of TPM - the pilot installation - there is a better know-how about the implementation available and the schedule

[143] (Brunner, 2014)

can be adjusted. For this, it is not necessary to structure every detail of the entire plan as it is not possible yet to assume the time needed for each element.

8. Develop plan for pilot installation of TPM

   The pilot installation is crucial for the success of TPM. As there is a use of methods that have never been applied before to the company it is important to plan this stage carefully. The installation is dependent on the strategy in the first part. For example, if the TPM-EM is the beginning part, the focus will be on trainings concerning problem analysis and solutions further in the improvement of the equipment. Another first step could be to avoid maintenance and establish project teams that set up a PM approach for this.

9. Develop detailed plans for further installations of TPM

   Although this step belongs to the planning part, it is being shifted after the pilot installation. As there was no reliable data about TPM installation yet, it was not possible to organise a valid plan for it. As soon as the first installation is in progress, there is information about the process and its duration available. This data will be used to for more precise planning of the further installation.

10. Presenting at management

    Before starting with the first installation of the pilot TPM the management needs to agree with it. For this the actual data and the plan will be presented to the management, that needs to confirm the approval of the next step: The pilot installation of TPM[144].

4.2.2 Pilot installation of TPM

The pilot installation is the first installation of TPM in the company. Since there is no experience in TPM yet, the focus is on a machine or a division where well prepared data for the feasibility analysis is available. Choosing a division with high motivation for TPM supports the process as well. Besides these factors, the size of the division has an important role as well. The bigger the division, the more difficult is it to keep an overview. For this, it should be considered to start first with a size of 50 to 100 employees at the most. The idea of the pilot installation is to gain information and to be able to test some elements. It is not possible to finish the TPM in the pilot installation before implementing it to other machines or divisions as this would take two to three years. This is more of a trial and error approach, learning from mistakes before

[144] (Hartmann, 1998)

adapting it to other parts of the company. This means the pilot installation is a time frame of approximately three months ahead of the rest of the TPM installation.

The pilot installation does however require working groups. The purpose should be to consider the feasibility analysis. In the following steps, the installation of the three elements; TPM-EM; TPM-PM; and TPM-AM will be introduced separately.

- Installation of TPM-EM
- Installation of TPM-PM
- Installation of TPM-AM

I) In most of the companies the TPM-EM is being implemented first. The collected data in the feasibility analysis provides the TPM-EM installation with information. As it is difficult to say where to start, the OEE can be taken and analysed. The highest losses can be considered as the first elements that should be optimised.

The optimization process can consist of different steps, depending on the size of the production line. If the production line consists of more machine the following method can be used to help setting the priorities.

The optimisation process can consist of different steps, depending on the size of the production line. If the production line consists of more machine the following method can be used to help setting the priorities.

Analyse current output of each machine (CO)

Analyse for each machine the current OEE (COEE)

Set a new OEE (NOEE) based on the loss analysis and set goals

Calculate the in terms of percentage possible improvement by comparing NOEE and COEE

Recalculate the temporal CO of each machine into the possible current output (PNO)

Analysis the bottleneck of the production and set up a new model of output that has to be determined (NMOD)

Analysing the needed improvement in total and break down for every machine the new equipment effectiveness determined (NEED)

Set priorities for TPM, the higher the percentage, the higher the priority

Besides the analysis in terms of percentage, there is also the possibility of analysing the losses with the help of an abc or pareto analysis.

If the origin of a problem was found, the source for it has to be clarified. The challenge is to remove the origin of the problem and not to simply prevent it through quick maintenance. The suggestions and solutions of the team are collected and carried out on the equipment. After significant changes to the machine or the equipment a new OEE of the machine should be made. A tool to avoid loosing the overview is the OEE improvement check list. The list contains actions and machine losses and helps assists the team considering each element. For this, the company can make use of Table 5 which contains the important influential factors for each element.

II) To avoid equipment, malfunction and keep it in a good condition, TPM-PM is the best option. The challenge is the execution of PM. The operator and maintenance staff will have new tasks to do accomplish and must agree on fulfilling those. For this, there is an agreement between the employees needed to operate these new tasks and, for this it has to be questioned if they are already able to fulfil these tasks properly.

To guarantee successful production the machines need planned downtimes. However, the time that is needed for good PM is compared to a malfunction by far less, and will convince the production manager to do operate PM.

III) TPM-AM is a concept which can meet some resistance amongst the employees. At the beginning the whole machine and operation system needs to be cleaned. The cleaning process should be structured into different tasks and a definition of whether the operator or the maintainer will be responsible for it. The idea is that it is more motivating to keep a clean machine decent than a dirty one. The next logical step would be to check the machine for abrasions and wear. Typical parts are tubing connections, components, security items and other parts. Collecting the parts that have to be cleaned helps to set up a check list. However, it is important that the employees have the necessary skills to clean the parts and assemble the machine properly again. It is also possible that the operators prepare small maintenances to avoid longer break downs.

Besides the challenges of resistance, the effort and the precise work, TPM-AM is a chance to motivate the employees and reduce costs in the long term[143].

The Japanese Institute of Plant Maintenance (JIPM) suggests seven steps for the implementation of autonomous maintenance. The above mentioned can be found in these steps and help to structure the process. The steps relate mainly to the operators, but also to the equipment as it gets improved indirectly as well.

1. Basic cleaning

The Basic cleaning is completed mainly at the main parts of the machine. Weaknesses can be seen easier at a clean surrounding than at a dirty one. Oil leakages mean a loss of pressure which in turn means a breakdown in the long run. The oil can only be spotted if there is a clean surface. This makes the basic cleaning crucial although it is simple. The weakness spots that are found during the cleaning process are collected and marked. The mark is set at the machine and has three different colors, depending on the responsibility. Tasks for the maintenance employees, the operator personnel and the ones that are difficult to reach or represent a safety issue.

⇨ Recognize tiny small problems before they get big.

2. Countermeasures to the sources of problems

After recognising the issues around cleaning machines, the search for possible solutions begins. For this, any source of dirt or pollution is analysed so that it might be removed. Besides this, there are also efforts made to find new ways to improve parts that are difficult to clean and to reduce the time needed for lubrication and cleaning.

⇨ Keeping a machine clean is better than cleaning it.

3. Definition of cleaning and lubrication standards

As soon as the machine is clean, the goal is to keep it in this condition. Defining new cleaning standards and periodic cleaning intervals help to support this. Employees who fulfil these tasks help to define standards and to find specific areas that need improvement. This could be a part that is challenging to lubricate or a part that cannot be measured properly.

⇨ Cleaning and lubrication standards have to be easy and non-bureaucratic.

4. Implementing a general inspection

This step is necessary to ensure a general inspection of the whole system. Employees who work with a machine need to understand how it works and how to maintain it. For this, the employees need training. A possibility how to organise training was mentioned before. Trained employees can notice deviations of the normal production process and help to react faster to disturbances.

⇨ Operators understand their machines the best.

5. Autonomous inspection

The standards for cleaning, lubrication and inspection that were accomplished in the first step are used for the next part. Based on experience that was made after implementing a general inspection and a cleaning standard, new standards can be defined and adopted. There is also a need to define who is responsible for the inspection, either the operator or the maintainer. For defining the new standards, the following questions should be asked:

- Where is an action needed?
- What is the condition, that shall be reached with the action?
- Which method is used to reach the condition?
- Which tool, knowledge or skills are needed?
- How much time does the action take?
- Who is responsible?

6. Organisation and order

Whereas the steps one to five focus on activities of the operators and their operating system, this step extends the activities to the whole surrounding. There are standards determined on how to organise the workplace in which test and measuring instruments, tools, but also the tasks of the employees are collected and presented clearly.

7. Complete autonomous operator maintenance

As mentioned above the next step are work groups that meet with one another and ensure a continuous improvement process[145].

4.2.3 Plant-wide installation of TPM[146]

The pilot installation helps to understand how the employees react on different methods. Approximately three months after the start of the pilot installation, it is possible to apply the learned lessons to other parts of the plant as well. Based on the new information, the plan for further implementation of TPM can be adjusted and prepared in more detail. The organisational structures of TPM is applied for the whole plant. New groups need to be formed, new TPM responsibilities are needed, employees are provided with trainings and the achievements of TPM need to be shown.

[145] (Brunner, 2014)
[146] (Hartmann, 1998)

4.3 Overall Equipment Effectiveness (OEE)

As mentioned above before the overall equipment effectiveness is one of the key figures of TPM. For this, an overview should first be given alongside the advantages of overall equipment effectiveness. Before the influences, the so called ‘six big losses’ are described and connected to the calculation of the OEE. Afterwards, examples help to cluster the influences on OEE and its metrics. As soon as the concept is being described the focus will be set on benchmarks to interpret the receiving data and finally some challenges and problems that can occur with the calculation of OEE are presented.

4.3.1 What is Overall Equipment Effectiveness?

Overall Equipment Effectiveness is a characteristic for the manufacturing productivity. The advantage of this method is, that it identifies the manufacturing time that is truly productive by taking care of six big losses. The six big losses can be clustered into three main categories: availability, performance and quality. The multiplication of these three variables builds upon the result of the overall equipment effectiveness. The OEE identifies the manufacturing time that is truly productive. A score of 100% would mean that the production line is producing only good parts without any losses. A score of 85% can be considered as very good. By measuring the OEE the company gets an insight into possible losses and is able to adjust the necessary parameters and get an insight into how to increase efficiency. For this, it is needed to understand the formula of the OEE and its influences to increase the score (1)[147].

$$OEE = Availability \times Performance \times Quality \tag{1}$$

Formula 1: Overall Equipment Effectiveness

[147] (Schmitt, Pfeiffer, 2015)

4.3.2 The six big losses

As mentioned before, the OEE is dependant on the six big losses that influence the effectiveness.

1. Breakdowns: Defective products that decrease the productivity that results in a time or quality loss.
2. Set-ups/Changeovers: If the production of one item is finished and the following item has different requirements, the adjustment of the equipment is considered as adjustment time losses.
3. Idling and minor stops: Interruption of temporary malfunction or idling of a machine.
4. Reduced speed losses: The difference between the equipment's designed speed and the operating speed.
5. Start-up losses: Machine startup stabilisation that occurs in early stages of production.
6. Yield, Rework, Scrap: Malfunctioning production equipment that causes quality defects and rework.

The availability is dependent on the first two losses, also known as 'downtime losses'. The performance is dependent on the third and fourth losses, also known as 'speed losses' and last but not least, the quality is dependent on the final two losses, also known as 'losses due in terms of the defects'. As there are now the known the dependencies for the three mentioned metrics: availability (2), performance (3) and quality (4) the OEE (1) can be calculated in the following way[148].

$$Availablity = \frac{loading\ time - downtime}{loading\ time} \tag{2}$$

Formula 2: OEE – Availability

$$Performance = \frac{theoretical\ cycle\ time\ \times\ processed\ amount}{operating\ time} \tag{3}$$

Formula 3: OEE - Performance

$$Quality = \frac{processed\ amount - defect\ amount}{processed\ amount} \tag{4}$$

Formula 4: OEE – Quality

[148] (De Ron, Rooda, 2006)

Table 6 is giving an impression of possible events that can occur in the production process and help clustering the influences on the overall equipment effectiveness[149].

Table 5: Overview OEE losses & examples[149]

Loss Event	OEE Metric	Example of Loss Category
Breakdown	Availability	• Equipment Failures, • Tooling Damage, • Unplanned Maintenance
Changeovers		• Process Warm Up, • Machine Changeovers, • Material Shortage
Idling / Stops	Performance	• Product Misfeeds • Component Jams • Product Flow Stoppage
Reduced Speed		• Level of Machine Operator Training • Equipment Age • Tooling Wear
Start-up losses	Quality	• Tolerance Adjustments • Warm Up Process • Damage
Yield, Rework, Scrap		• Assembled Incorrectly • Rejects • Rewor

4.3.3 Analysing the OEE and its improvement

Understanding the OEE, its weaknesses, losses and parts with a potential to improve, is necessary to increase the OEE. For this, the total losses of a machine must be analysed and systematically identified before being adjusted and corrected in an action plan. It is important to know that the OEE does not give any information about the source of losses. Moreover, it gives an overview of the origin and through this, builds a basic of decisions for improvement strategies. A diagram with the time shares in percentage on the vertical and the different metrics as well as their influences on the horizontal helps to get an overview and to analyse the OEE[150]. An example for such diagram is given in figure 32[151].

[149] (Exor International, Inc., 2014)
[150] (Brunner, Wagner, 2016)
[151] (Williamson, 2006)

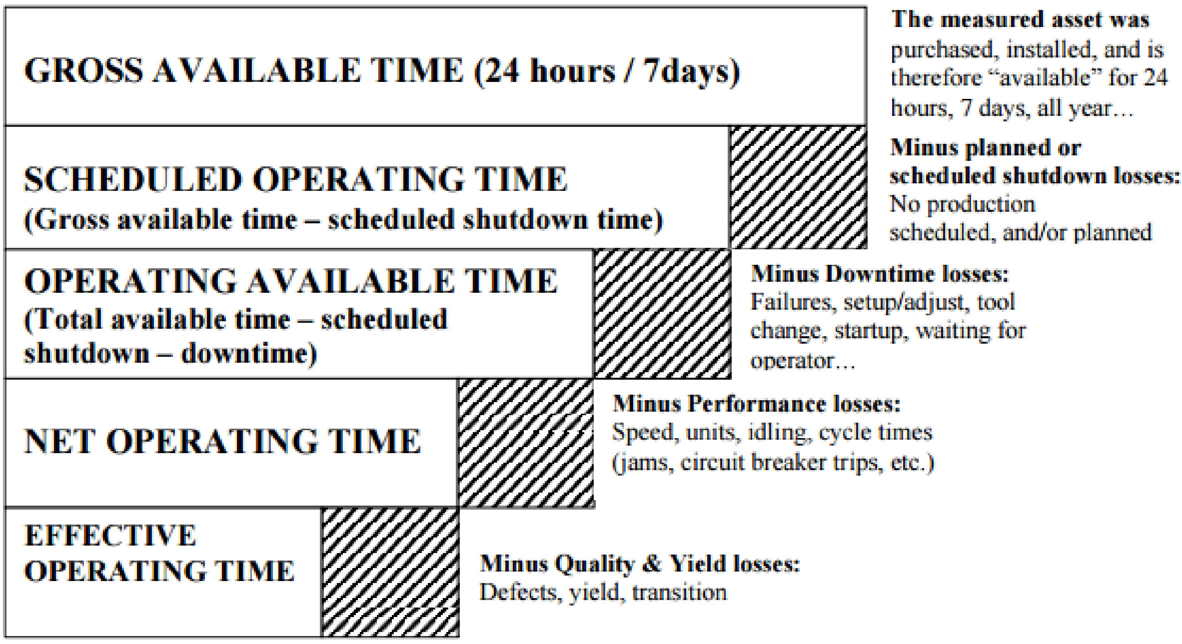


Figure 32: Exemplary Diagram of OEE[152]

The diagram gives the possibility to take a closer look into the processes and its weaknesses. It is possible to merely calculate all the different impacts without plotting them. The gross available time consists of the time in which the machine is available, which is in general 24 hours and seven days a week. From this the time is subtracted for which the company is not producing, in general holidays or weekends. Furthermore, the planned downtimes for changeovers or workshops have to be subtracted. The result is the scheduled operating time. As not every event can be foreseen, there are unplanned downtimes as well as failures, adjustments or tool changes. If these are subtracted from the scheduled operating time the available operating time is received. The net operating time considers speed losses as well. Finally, the effective operating time is reached as soon as the losses concerning quality defects and yields are considered as well. The single formulas are presented below and help to uncover weaknesses quickly and simply. It is important to mention that only the OEE can also make use of theoretical calculations for shift models. The OEE1 (5) should not be used for benchmarks as the denominator is chosen randomly (5). In the GrossOEE it is possible to take planned and unplanned losses into account (6), while the TEEP (Total effective equipment productivity) only considers the unplanned losses (7)[152].

[152] (Williamson, 2006)

$$OEE1 = \frac{Effetive\ Operating\ Time}{Gross\ available\ Time} \tag{5}$$

Formula 5: OEE1

$$GrossOEE = \frac{Effetive\ Operating\ Time}{Scheduled\ Operating\ Time} \tag{6}$$

Formula 6: Gross OEE

$$TEEP = \frac{Effetive\ Operating\ Time}{Operating\ Available\ Time} \tag{7}$$

Formula 7: TEEP

The international institute of TPM released a guide to improve the OEE and its influences. The overview of possible improvements is given in table 7[153].

[153] (Hartmann, 1998)

Table 6: Improvement of OEE[154]

Availability	**Avoiding of breakdowns** • Improvement of equipment • Improvement of preventive maintenance • Implementing autonomous maintenance **Reduction of Changeovers** • Limitation of test runs • Reducing calibration time • Automation of calibration time • Avoiding and reducing make-ready's
Performance	**Reduction of Idling / Stops** • Improve material flow • Avoiding misconduct • Remove disturbances in material supply • Autonomous inspection • Implementing cleaning and lubrication procedures **Avoiding losses due to machine speed** • Exchange of worn parts • Balancing all rotating pieces • Improving lubrication
Quality	**Increasing product quality** • Ensure Equipment accuracy **Avoiding Yield / Reword / Scrap** • Implementing static process control • Improving equipment settings • Implementing equipment surveillance • Setting a plan for tool changes • Implementing autonomous inspection • Equipment improvement

154 (Hartmann, 1998)

4.3.4 Benchmarks

In the introduction to OEE we got to know that it has been explained that a good value for the OEE would be a score of 85%. If we take this as an average score, over all the different industries, it is seen as correct. By taking a closer look into different scores it is proven that it depends on the branch and the industry the company is working in. A study by Matthew Littlefield in 2012 shows, that the benchmark of OEE is dependent on the industry. For instance, the median in the Aerospace and Defense industry is at a score of 0.75 while the score of the medical devices industry is at 0.91. The results of the study are shown in the figure 33.

However, more important than the general OEE is the score of each metric. Depending on the industry, different metrics can be considered as good or median. For the industrial equipment industry, for instance, the performance is rather above average and has a score of more than 0.90 on average. This leads to the conclusion that in this industry the availability and speed has a higher potential to increase the OEE than the performance[155].

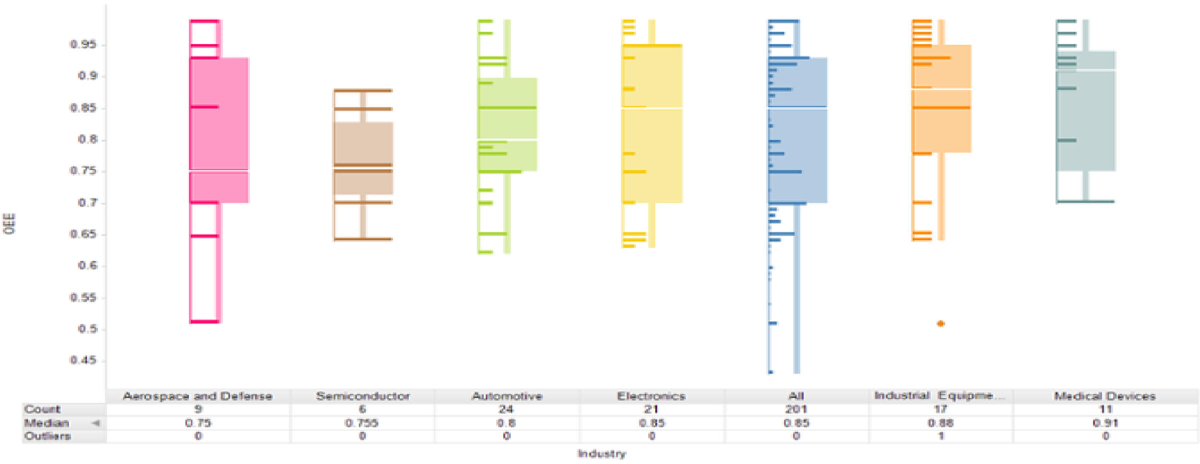


Figure 33: OEE Benchmarks[155]

The results of the Meta-analysis matches with the assertion of Nakajima, who invented the idea of OEE. He stated that under ideal conditions there should be the following values: Availability > 0.9, Performance > 0.95 and Quality > 0.99. By multiplication of the different metrics the OEE score of 0.85 can be achieved[156]. Other investigations of the OEE show that an OEE between 0.30 and 0.80[157] or a value less than 0.50 seems to be more realistic[158].

The different results lead to the conclusion that scores above 0.85 are realistic and should be strived for. However, the metrics can differ depending on the industry.

[155] (Littfield, 2012)
[156] (Nikajima, 1989)
[157] (Ericsson, 1997)
[158] (Kotze, 1993)

4.3.5 Challenges and problems[159]

Besides the mentioned advantages, there are challenges and problems of the OEE as well. As already concluded the metrics concerning the OEE are highly dependent on the industry and the branch a company works in. Therefore, benchmarking metrics over different industries is not possible.

Furthermore, the OEE measures the effectiveness of every single equipment performance and not how effective the total aggregation of the manufacturing process is. This impacts the comparability as well. Only with similar plants, with comparable equipment, that manufacture similar products with similar materials, is it possible to make use of the OEE as a benchmark. To improve the whole effectiveness by the OEE it is necessary to track the performance of each equipment piece or element. For this, the whole process has to be understood. Another important element is the way in which the variables are measured. A comparison between similar products with comparable materials is only possible if the measurement of all influences is standardised. Finally, it is an element that helps to understand the weaknesses in the production process by analysing the effectiveness of each single part. It does not give any solutions for the deviation.

4.3.6 Summary OEE

OEE examines factors that influence the equipment effectiveness and by this it is more than a maintenance measuring system. Whereas there are six big losses, maintenance influences directly only the planned maintenance and the number of breakdowns and failures. The other losses are impacted by operation roles as well. For this, the OEE is one of the main elements of Total Productive Maintenance, in which the whole organisation is taking a focus on eliminating losses. By taking the whole production and its influences into account it is a holistic classification number that considers the whole influences on the production process. By measuring the effectiveness of each production unit, the whole manufacturing plant can be improved. However, it is only measuring the performance of the production pieces and does not offer any solutions. Furthermore, a benchmark of the OEE is only possible when considering similar plants, with similar equipment, that manufacture similar products with similar materials.

In industry, the high investment costs for equipments require an unhindered operation of the mechanical equipment. In this case, the production of wafer machines shall be investigated to understand reasons for failure and lower overall equipment effectiveness.

[159] (Brunner, Wagner 2016)

4.4 Ishikawa Diagram

A simple method to identify the cause of a problem is the so called 'Ishikawa diagram', after the inventor Kaoru Ishikawa or also known as 'cause-and-effect diagram' or 'fishbone diagram'. It helps to identify the main causes or side causes for an effect clearly both positive or negative influences. The structure is shown in figure 34.

Procedure:

1. Detailed description and information of the investigated problem, e.g. content, place, time and extents. The problem is shortly mentioned on the right side with an horizontal arrow running to it.
2. Brainstorm the main categories that might have cause the problem, e.g. Method, machine, manpower, material (measurement, environment). In terms of technical problems the four mentioned causes are considered as the major causes[160]. However, the major causes can also be extended to more causes to 7M[161] or 8M[162]. The categories are connected by branches or bones to the arrow that is leading to the problem.
3. The next step is brainstorming the possible causes of the problem and assigning them to a category. These causes are branches again from the main categories.
4. After identifying possible causes, the causes have to be questioned and analysed. This creates sub-causes that further branch off from the main causes.
5. As soon as the team runs out of ideas, a weighting of the different causes is completed to evaluate the main cause[160].

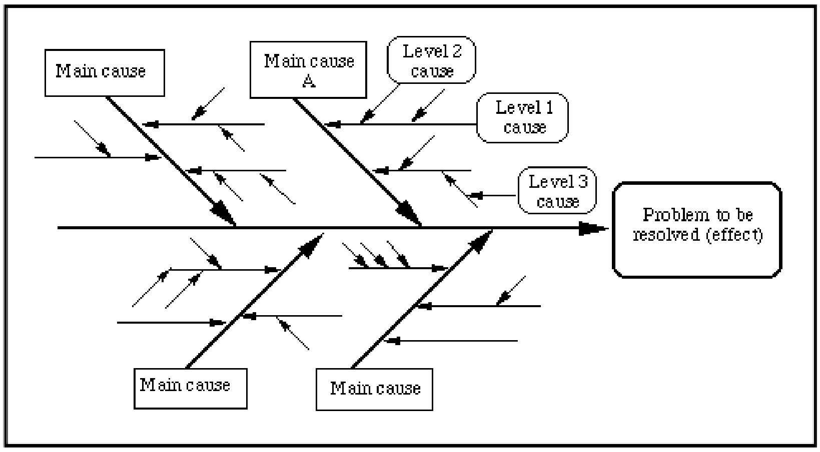


Figure 34: Ishikawa Diagram[163]

160 (Schmitt, Pfeiffer, 2015)
161 (Brunner, Wagner, 2016)
162 (Barthelmes, 2013)
163 (American Society for Quality, 2017)

4.5 Methods of data collection and evaluation

Developing maintenance concepts and strategies is highly dependent on data. For this, a scientific method for the data collection, its sources, its interpretation and its analysis is necessary to ensure a valid and reliable concept and strategy.

4.5.1 Data collection possibilities / procedure

To identify mistakes and weaknesses of a product there are different possibilities. One possibility is series testing. In terms of the immense time needed for tests, there are some limitations in this analysis. Furthermore, the manufacturer is rarely capable of predicting different varieties of usage and can not derive any demands in quality in this field. Another option is the environmental simulation. The idea is to accelerate the aging process of the material and the machine to derive any information. However, the only valid possibility is to gather information in the market by field analysis.

The information made during the use of the product can flow into the production of other machines as well. Only in use, the manufacturer will receive any information if the set goals of quality and reliability were reached.

To gather this information, there is a need for the systematical collection and analysis of field data. In general, the service and after sales departments are responsible for this and ensure that the manufacturer receives information concerning the reliability and quality. The quality of the data is highly dependent on how reliable the customer is in collecting the data and doing the maintenance. For example, in some cases the repair of a part is too complex and the whole part is in turn changed. The reason for the breakdown cannot be identified in this way. Taking this into consideration, the different data sources have to have to be considered as well[164].

4.5.2 Data sources

As field data is the most representative data to evaluate the quality and reliability of a machine, the focus is set on gathering data in this section. Three sources are available: the customer, the service and automatic data recording.

Information of the customer can be gained by through reclamations, customer log books, spare part orders from the customer or warrantee demands. In most cases the data flow is the best until the end of the warrantee as the manufacturer benefits mainly from the customer's data collection. One possibility might be an offer from the manufacturer to solve problems quickly and efficiently with corrective measures based on the source of the problem.

[164] (Schmitt, Pfeiffer, 2015)

The data of the service is characterised by a high level of detail as specialised employees were collecting it. The data is collected either in maintenance works, commissioning, diagnostic reports, spare part demands or acceptance reports.

Automatic data recording is enabling the product itself to collect data. Typical elements for this are sensors, measurement systems or condition based reports. Depending on the point of view there are different advantages and disadvantages existing. As mentioned above, service employees take down specific data in a high detail, while automatic data recording systems specify which data is important and which is not. Analysing this amount of data can be time intensive and complex. Although it is time intensive the huge amount of information can help to find the origin of a problem which might be challenging by having only the information of the customer available. This leads to the conclusion that depending on the type of the machine or the product, the source of data should be evaluated and analysed. While service companies provide their data mainly from customers, many manufacturers collect their information with automatic data recording[165].

4.5.3 Data collection

The collection of field data needs a standardisation, while in chapter 2.1.5.3: Evaluation of performance and results of maintenance, a standardised table has been introduced, the formalisation is now more about a whole data collection in field analysis that can made. Besides the systematical collection of data, it is also necessary to pass the information to the product developing departments, that the employees are able to react on problems. However, it is necessary to evaluate and analyse the data to gain information concerning the product behaviour in use. Depending on the product and the company, the data can be collected either digitally or in sheets[165].

Data that include information concerning frequency and type of malfunction shall be derived from the above-mentioned data collection. For this, the data has to be structured and clustered by different types of data.

The failure data includes information concerning frequency and type of malfunction. For this, the huge amount of data has to be structured and clustered. The identification of the machine can be accomplished through parameters like machine number, customer or production place, whereas the failure data contains information concerning the type of failure, failure part or failure reason. This data is completed by the master data that has information about the machine type, the model, the product number and indication. By applying the formula (1) - (4) the OEE can be generated. This information shall be clustered into the introduction of Ishikawa diagram in chapter 4.5: Ishikawa Diagram to identify different causes for the effects. By analysing the

[165] (Schmitt, Pfeiffer, 2015)

production time over a specific time slot, the amount of produced goods can be derived as well as the value creation being able to be calculated.

4.5.4 Data interpreting and minimising time loss

The interpreting of the data shall assist in minimising losses in the long term. For this, the different lines are being compared. Taking into consideration that the investigated object is the same machine, a valid benchmark can be received. By having the different values of each line, the assumption that it is possible to reduce the time needed for adjustment, start-up, breakdowns or mechanical errors can be made. By comparing the theoretical OEE of each line to the actual OEE based on benchmarks, the difference is that the costs result in non-optimal equipment performance. By multiplying the value creation per hour with the time, the machine could be available and losses concerning breakdowns, changeovers, malfunction and quality issues can be received. The result in the long term will be the reduction of reasons causing losses. Aside from this, the values for the OEE can be used to control the efficiency in real time. Depending on the results there is even the possibility to train the employees constantly or to outsource the maintenance to a provider.

4.5.5 Analyzation of maintenance costs

Based on the data there, the necessary work load, working experiences, skills and tools to ensure an optimal equipment efficiency shall be derived. This shall be compared to the benefits of the OEE. Furthermore, the costs for the maintenance service by the manufacturer shall be analysed assuming economies of scale and scope. Afterwards, the maintenance costs need to be compared to the costs the manufacturer would have in offering a maintenance service. The following elements have to be considered:

- Analysis of skills, trainings, maintenance hours and equipment
- Analysing the costs for the manufacturing service (travel costs, knowledge, response time)
- Comparing the results to the OEE
- Adopting constraints from simulations of the latest study by A. Weissenbach and comparing his assumptions[166]

To sum up, the question is whether it is better to outsource the maintenance or to keep it within the companies.

[166] (Weissenbach, 2016)
[167] (Murthy, Jack, 2014)
[168] (Kim, Djamaludin, Murthy, 2001)
[169] (Murthy, Djamaludin, 2001)

4.6 Maintenance Service Cost Analysis

4.6.1 Assumptions

To simplify the cost analysis the following assumptions are made:

1. All lines are alike in terms of their usage.

2. All items are statistically similar

3. The customer reports each failure immediately to the service agent.

4. There are no invalid claims.

5. The time to fix a failure is sufficiently small in relation to the mean time between failures. This leads to the assumption that it is zero.

6. The OEM has the needed logistic support to carry out maintenance without delay.

Although an incentive contract might be beneficial concerning the incentives to increase the availability and decrease the maintenance activities, this type of contract needs an enormous background of data and time. As this is temporally not available, the focus shall be set on a performance contract. This matches the key performance indicator OEE.

To evaluate the costs for the maintenance service agreement both parties need to be investigated.

4.6.2 Customer

To identify the costs for the customer, the following data is needed. As the maintenance concept aims to increase the performance the costs for production have to be taken into account as well. This means primary, secondary and tertiary resources. Besides this the maintenance costs and costs for spare parts have to be part of the calculation as well. For this see table 8.

Table 7: Costs for customer (own depiction)

General Data
How many hours per day will the wafer production line be in operation?
How many days per year will the wafer production line be in operation?
How much does the square meter cost per month in EUR?
What is the average net wholesale price per kg product in EUR?
Labour Costs
What is the hourly salary for one operator in EUR at full cost?
What is the hourly salary for one maintenance technician in EUR at full cost?
Energy Costs
Do you use Liquid Petroleum Gas (LPG) or Liquid Natural Gas (LNG)?
What does liquid gas (LPG) cost per kg in EUR?
What does electricity cost per kWh in EUR?
What does compressed air cost per m³ in EUR?
Raw Material Costs
Wafer Batter: What does flour costs per kg in EUR?
Wafer Batter: What are the costs for fat, oil and other ingredients per kg in EUR?
Line Specifications
Number of baking plates per line
Baking plate width in mm
Baking plate length in mm
Average weight per wafer sheet in g
Average baking time of the oven in min
Energy consumption, labour & space requirements
Liquid gas consumption per oven ber kg wafer sheet (kg LPG/kg wafer sheet)
Electricity consumption in kW/h
Compressed air consumption in m³/h
How many m² space be required in total?
How many operators will be needed in total?
Line availability and efficiency
What is the line availability in percent?
What is the line efficiency in percent?
What is the baking waste in percent?
What is the cutting waste in percent?
Maintenance
How many man hours per year, per line, do you spend for maintenance?
How much is the spending for spare parts and consumables (grease, oil) per year, per line in EUR?

4.6.3 OEM

To data needed to calculate the costs for the customer, is shown in table 9.

Table 8: Costs for OEM (own depiction)

General Data
How many hours per day will the wafer production line be in operation?
How many days per year will the wafer production line be in operation?
Labour Costs
What is the hourly salary for one maintenance technician in EUR at full cost?
How many maintenance technicians are needed per line?
Maintenance
How many man hours per year, per line, do you spend for maintenance?
How much is the spending for spare parts and consumables (grease, oil) per year, per line in EUR?

4.7 Conclusion

The different maintenance service concepts were introduced in table 5. Each introduced concept has its own advantages and disadvantages. Whilst the design for maintenance helps to reduce maintenance activities in future manufactured equipment and spare parts, it is less benefitial for the short-term increase of efficiency. As mentioned above, most of the SMEs have not the financial possibility to buy a new machine. For this, there is a need for a maintenance service concept. The pro active maintenance concept takes this into account. Although, it consideres work planning, scheduling and execution and further a performance measurement and a maintenance strategy, it does not consider different outsourcing scenarios, a maintenance concept, any causes and effects or a possible solution. This makes it necessary to extend the currently existing concepts and combine different aspects to fulfill those needs. In table 10 different methods are compared to one another and a final picture of the maintenance service concept and its possibilities are given.

Table 9: Comparison of methods (own depiction)

Task	Maintenance Framework concept	TPM	OEE	New Concept
Outsourcing scenarios	-	-	-	+
Work planning	+	+	-	+
Work scheduling	+	+	-	+
Work execution	-	+	-	+
Maintenance Concept	+	-	-	+
Maintenance Strategy	-	+	-	+
Implementation	-	+	-	+
Causes and Effect	-	-	+	+
Possible Solution	-	-	-	+
Performance measurement	-	-	+	+
Continous Improvement Process	-	-	-	+
Short-term increasing of efficiency	-	+	+	+
Long-term increasing of effectiveness	+	+	+	+

As the demands for the service maintenance concept are known now, the maintenance service concept has to be designed. For this, the development is aligned on the framework for maintenance concept development by Waeyenbergh, Pintelon and Gelders.

The first step takes care of the cpmpany's strategy and scope. Crucial in this step is the scenario planning of the maintenance activities and which activities are being considered to outsource. In the next step the technical analysis helps to identify the most important systems and its critical components. As soon as the critical systems and its components are known, the maintenance policy decision tree takes the different types of maintenance, redesign and the condition measurement into account. Further, the decision for the maintenance concept or better for the maintenance strategy has been structured on TPM. RCM and BCM are highly complex which is a disadvantage for SMEs. Furthermore, the LCC approaches are excluded because it is a rather theoretical approach. Besides this, TPM aims towards cost reduction and increasing the productivity which is assumed to be suitable for a service maintenance concept as the goal of TPM is to increase the productivity and reduce the costs. These conclusions are based on the comparison of the different concepts by Waeyenbach and Pintelonin 2002 mentioned in chapter 3.2.5: Conclusion.

The implementation of the concept should take place in three phases. First the installation is planned and prepared. Afterwards there is a pilot installation and two months to three months later, the plantwide installation.

The performance measurement is done with the OEE. As the OEE is one of the most important effective KPIs in performance measurement, it was considered as the best option to make use of this KPI in combination with the benefits of TPM. A comparison of the important measures for an optimal production quantity is shown in table 11. Not all necessary information in terms of an performance indicators are covered by the OEE. The ones which can be calculated by the included information of the OEE data are described with the following signature: '+/-'.

Table 10: Comparison of important measures for KPI (own depiction)

Important measures for KPI	OEE
Total cost of maintenance / total production cost	-
A (availability) = (planned time - downtime)/planned time	+
P (production rate) = (standard time/unit)x(unit produced)/operating time	+
Q (quality rate) = (total production – defective quantity or number)/total production	+
Mean time to repair (MTTR) = sum of total repair time/number of breakdowns	+/-
Mean time between failure (MTBF) = number of operating hour/number of breakdowns	+/-
Maintenance breakdown severity = cost of breakdown repair/number of breakdown	-
Maintenance improvement = total maintenance manhours on preventive maintenance jobs ÷ total manhours available	+/-
Maintenance cost per hour = total maintenance cost/total maintenance man hours	+/-
Man power utilization = wrench time/total time	-
Manpower efficiency = time taken/planned time	+
Material usage/work order = total material cost/number of work order	-
Maintenance cost index = total maintenance cost/total production cost	-

Besides the adopted performance measurement of the OEE and the implementation of TPM, the continuous improvement process needs to be described as well. Although, TPM is considering as a continuous improvement, it is not described in a detailed way according to European norms. For this, the DIN EN 13306 for continuous improvement is considered alongside the proactive maintenance concept which is established on this norm. Finally, the above described methods are concluded and shown in figure 35 to get an overview of the needed steps.

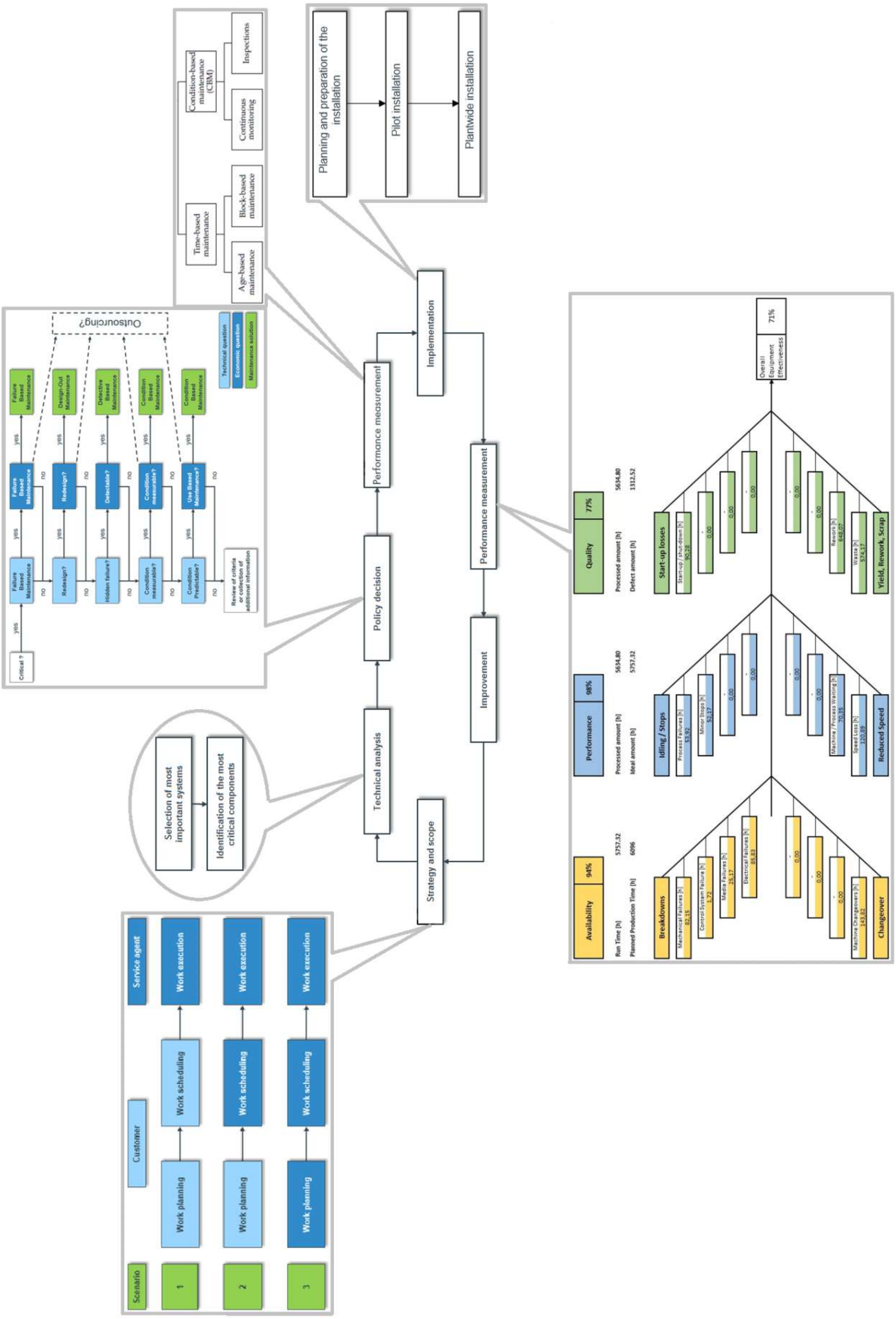


Figure 35: Framework of service providing maintenance concept (own depiction)

5 Validation

In industry the high investment cost for equipments requires an unhindered operation of the mechanical equipment. In the validation a manufacturing company and its customers shall be investigated concerning their maintenance behaviour. For this, the case study company is being introduced first, before the data collection, analysis and evaluation is being described.

5.1 The company's profile

In the following the OEM of this case study shall be described and further on which product the developed concept will be applied on.

5.1.1 General Information about Haas

The investigated company is called Franz Haas Wafer (FHW) and is part of the holding Haas Food Equipment. Part of the Holding is also Franz Haas CFT, Haas-Meincke and Haas-Mondomix.

The group has 1650 employees worldwide and has representatives in 67 countries. The headquarter is in Leobendorf.

FHW is the world market leader in the field of wafers and has 416 employees in the headquarter. It is a manufacturer for wafer machines and delivers them to customers in the food industry. The portfolio of the end products reaches from flat wafers, cones and soft biscuit, to pancakes and Belgium waffles. An overview is given in figure 36. To give an impression about the diversity of the machines, the types of plants, the different plants for each type and the subtypes will be presented for the wafers. The equipment for the end products is shown in figure 37. The wafer plants have specific plants again like the 'Flat & Hollow Wafer Baking Ovens', 'Downstream Equipment' and 'Wafer Stick Machin' see figure 38. Finally, the different types of baking ovens shown in figure 39[170].

[170] (Haas Online, 2017)

Figure 36: End products of FHW[171]

Figure 37: Equipment overview of FHW[171]

[171] (Haas Online, 2017)

Figure 38: Wafer Plants overview of FHW[172]

Figure 39: Baking Ovens of FHW[172]

172 (Haas Online, 2017)

5.1.2 The Machine line in focus

In the focus of the studies is the machine SWAKT. The reason for the choice is, that the machine is with approximately 330 ovens one of the most sold machines of the company. Furthermore, it is located in 54 countries and has been constructed in the years between 1982 and 2016. It is operating for more than 100 different companies that reach from small companies to world market concerns[173]. The probability of getting valid data is for this machine type the highest. It is used as a fully automatic large scale production unit for flat and hollow wafer sheets. The technical data:

- "gas-heated, 32 – 120 baking plate pairs, formats up to 350 x 730 mm
- self-supporting baking plates of grey cast iron for long service life, optimal energy exploitation and uniform wafer sheet colour
- two-chamber heating system effects efficient heating of the baking plates in the insulated inner chamber and longer service life of the mechanical parts in the outer chamber
- closed oven head for energy saving, low noise and increased safety
- automatic temperature control and operating data logging
- integrated exhaust system"[174]

5.2 Application of the maintenance concept

According to Horn in 2009, complete outsourcing of maintenance activities is more relevant for SMEs which is part of our case study. For this, complete outsourcing shall be considered as the best option. The concept starts with the development of the work planning and work scheduling by the service agent. To get a better overview of the current state, the tasks of all outsourcing possibilities this chapter is working on are shown in figure 40.

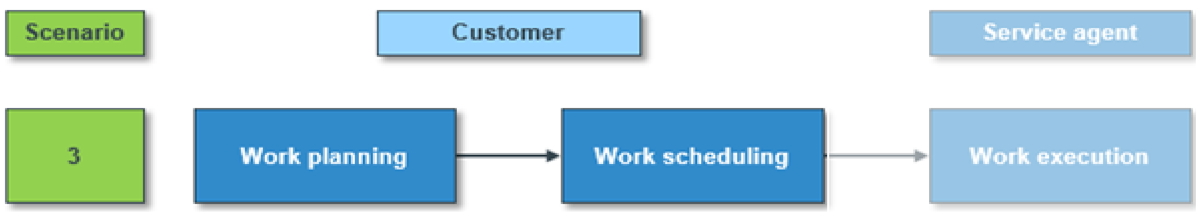


Figure 40: Outsourcing elements – part 1[175] (modified figure)

[173] (Haas Online, 2017)
[174] (Haas, 2017)
[175] (Murthy, Jack, 2014)

To ensure a better overview during the conception, the framework for concept development and each step that is currently worked on is highlighted at the beginning of each chapter.

5.3 Identification of the objectives and resources

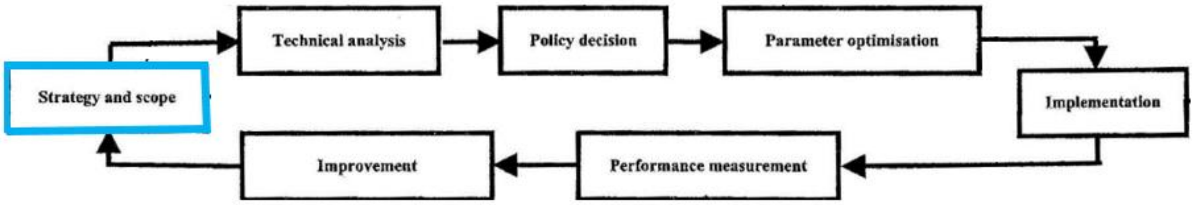


Figure 41: Maintenance concept development - part 1 (modified figure)[176]

After choosing the machine line, the maintenance objectives need to be determined. The objectives are derived from general demands to maintenance:

a) Ensure the safety and reliability of the equipment

b) Keep equipment in accordance with standards for the environment

c) Keep capacity, availability and quality at a desired level

d) If components deteriorate the system must be able to restore safety and reliability

e) Possibility to collect information to maintain availability, reliability and quality

f) Keep costs within the budgetary limitations[177]

Data analysis

Data that include information concerning frequency and type of malfunction shall be derived from the above-mentioned data collection. For this the data has to be structured and clustered by different types of data.

The failure data includes information concerning frequency and type of malfunction. For this, the enormous amount of data has to be structured and clustered. The identification of the machine can be done by parameters like machine number, customer or production place. Whereas the failure data contains information

176 (Waeyenbergh, Pintelon, Gelders, 2001)
177 (Waeyenbergh, Pintelon, 2004)

concerning the type of failure, failure part or failure reason. This information is completed by the master data that has information about the machine type, the model, the product number and indication[178]. By applying the formula (1) - (4) we get the OEE. This information shall be clustered into the introduced Ishikawa diagram in chapter 4.5 Ishikawa Diagram to identify different causes for the effects.

Data collection and evaluation

As mentioned above the focus of the studies is the so called machine SWAKT. To collect information from the field, the different companies that operate the machine were contacted via e-mail and asked to fill the document shown in 9.1 Annex – Questionnaire.

There is only one company that has recorded the data in a detailed way shown in 9.2 Annex – Date collection sheet for OEE. This data can be analysed. All the other companies did either not collecting the data in a proper way, didn't collect any data at all or were not willing to share it. The shared information helps to set up an OEE without having to collect data in the field.

The above-mentioned tasks that have to be done, if there is no data with the necessary information available, can thus be ignored:

- determining operations when model time is being measured
- how to measure, measuring by operator or by author
- planning how to implement the method
- publication and digitalisation of collected data

However, the different types of time need to be considered to guarantee a valid calculation of the overall equipment efficiency:

- start-up time
- set-up time
- production time

Besides this the following aspects and reasons for them need to be recorded as well:

- downtime
- idling / stops

[178] (Schmitt, Pfeiffer, 2015)

- changeovers
- breakdowns
- scrap and rework

The performance is measured in production hours. In one production hour the SWAKT oven is able to produce 2000 kg of wafers.

To determine if there is data available, there is a questionnaire for the companies that run the investigated object and can be seen in 9.1 Annex – Questionnaire. If there is no data available the data needs to be recorded in a suitable form. An example of the data collection sheet is given in 9.2 Annex – Data collection sheet for OEE.

The built-in or inherent performance defines the theoretical performance which the machine can do. The amount of production hours in 2015 is 8760 hours (365 days and 24 hours a day).

The required performance is aligned with the OEE as a benchmark. This represents and OEE of 85 %, which leads with a production rate of 254 days and 24 hours a day to a production amount of 5181 hours in the year 2015.

The actual performance of the lines is:

Line 1: 4322 production hours

Line 2: 5145 production hours

Line 3: 5431 production hours

The most important productivity goal is the above mentioned 85% production rate.

The data needed for the technical analysis is based on historical data of the company FHW. The amount of sold spare parts for the machine line SWAKT were collected over the last 30 years. Based on this information, the technical analysis, its selection of the most important systems and the identification. In general the needed information for the technical analysis can be provided by the OEM of the spare parts. They collect information regarding sold items, from which the most important systems and components can be derived.

5.3.1 Technical analysis

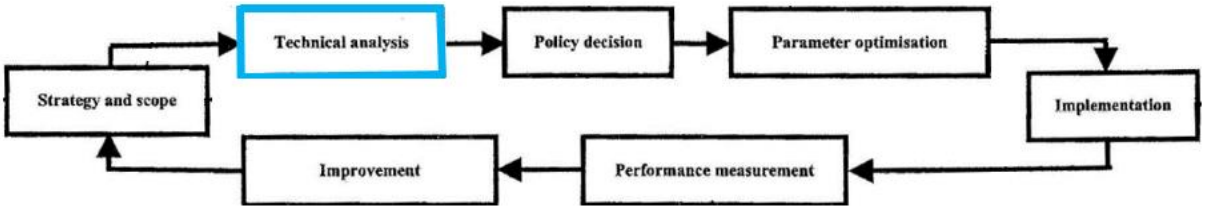


Figure 42: Maintenance concept development - part 2 (modified figure)[179]

The technical analysis consists of two main elements, the selection of the most important systems and most critical components thereof. For this, the most important systems have to be checked first. After analysing the influences and consequences of the system, the components that are part of the system can be focused on.

5.3.1.1 Selection of the most important systems

As the system is very complex it is neither practical nor cost effective to take the machine as a whole. To reduce complexity, the most important systems of the machine must be identified. This is done with the production, technical development, maintenance service employees and performance assessment employees. Furthermore, the data from the above mentioned downtime and breakdowns is being used. The spare parts that were needed to fix the reasons for the breakdowns were clustered along the most important system. The factors that lead to loss of equipment effectiveness are:

- Main drive
- Hand crank
- Pulse control
- Heating
- Baking tong
- Chain tensioning system
- Batter deposit
- Wafer take-off device
- Waste evacuator
- Exhaust gas aspiration
- Material (dough)

[179] (Waeyenbergh, Pintelon, Gelders, 2001)

5.3.1.2 Identification of the most critical components

Based on historical data, experiences and failures, the most critical components can be evaluated. For this the input from production and maintenance was crucial. The failure components are linked to the most important systems as shown in table 12.

Table 11: Most critical components (own depiction)

Most Important Systems	Most Critical Components
Main drive	Gearmotor Roller bearings or motors and gearboxes Main bearing
Hand Crank	Angular Gearbox
Pulse control	Drive chains Gear and chain weels
Heating	Blower Heating components Main burners Pilot burners
Baking tong	Running wheels Locking roller Hok roller Hook bearing Chain links Baking tong hinges Guide roller
Chain tensioning system	Running wheels
Batter deposit	Servomotor Gearbox Roller bearings or motors and gearboxes Batter pump
Wafer take-off device	Round belt drive Brush drive Roller bearings or motor and gearboxes Round belts Flange bearing Bearing of drive axle Reversing pulleys
Waste evacuator	Gearmotor Roller bearings or motors and gearboxes Gear and chain wheels Conveying chain Ball bearing
Exhaust gas aspiration	Exhaust blower
Material (Dough)	Viscosity Moisture Thickness of Waversheet Weight of Wafersheet

5.3.2 Maintenance policy selection

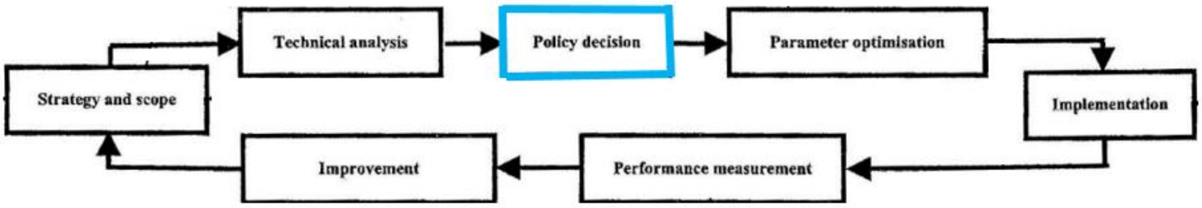


Figure 43: Maintenance concept development - part 3 (modified figure)[180]

The maintenance policy depends on the figure 28. This tree has been adapted to the case study and shown in figure 44.

As a line is producing 2000kg of wafers an hour, it is intended to have no breakdowns. Although failure based maintenance is theoretically possible it would not be economical in any case. This is the reason why it is not considered an option. The next possibility would be to redesign the system or the components. As the maintenance concept is intended for SMEs it is not an option to design the machine in a new way, as SMEs do not have the liquidity to buy a new SWAKT line for a great sum of money. This is the reason why a redesign is not considered as an option, as it is technical not possible to redesign the whole system. The next step in the decision tree is the hidden failure and if the failure is detectable. The investigation lead to the results that some failures can be avoided through inspection and lubrication. This affects the parts shown in table 13.

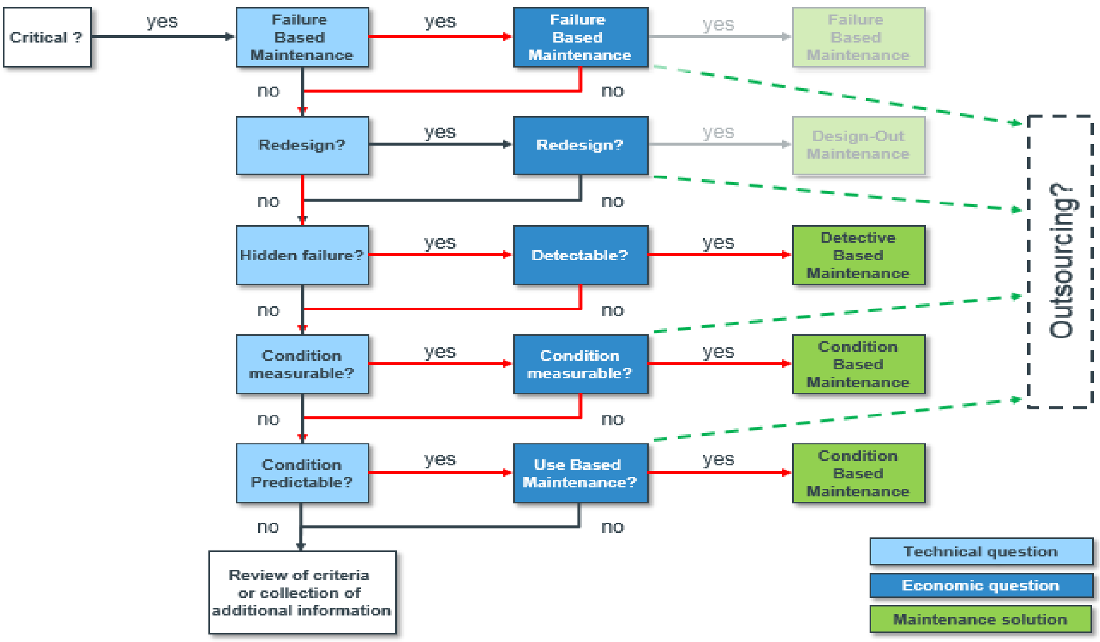


Figure 44: Adopted maintenance policy decision tree (modified figure)[180]

[180] (Waeyenbergh, Pintelon, Gelders, 2001)

Table 12: Detective based maintenance parts (own depiction)

Most Important Systems	Most Critical Components
Main drive	Gearmotor Roller bearings or motors and gearboxes Main bearing
Hand Crank	Angular Gearbox
Pulse control	Drive chains Gear and chain weels
Heating	Pilot burners
Baking tong	Hok roller Hook bearing Chain links Baking tong hinges
Batter deposit	Gearbox Roller bearings or motors and gearboxes Batter pump
Wafer take-off device	Roller bearings or motor and gearboxes Flange bearing Bearing of drive axle
Waste evacuator	Gearmotor Roller bearings or motors and gearboxes Gear and chain wheels Conveying chain
Exhaust gas aspiration	Exhaust blower

Some conditions are measurable and can be seen. This refers to the parts shown in table 14.

Table 13: Condition based maintenance parts (own depiction)

Most Important Systems	Most Critical Components
Chain tensioning system	Running wheels
Wafer take-off device	Round belt drive Brush drive Round belts Reversing pulleys
Waste evacuator	Ball bearing

Whilst the above mentioned parts are mechanical or electrical elements there are some failures that depend on the material. This means, that the condition of quality is predictable for certain parameters of the dough, as seen in table 15.

Table 14: Influences on Quality (own depiction)

Most Important Systems	Most Critical Components
Material (Dough)	Viscosity Moisture Thickness of Waversheet Weight of Wafersheet

The maintenance policy considered a whole in-house maintenance system. It is also possible to outsource some elements of the maintenance, while the inspection is done in-house. The benefits of outsourcing are discussed above.

5.3.3 Optimisation of the maintenance policy parameters

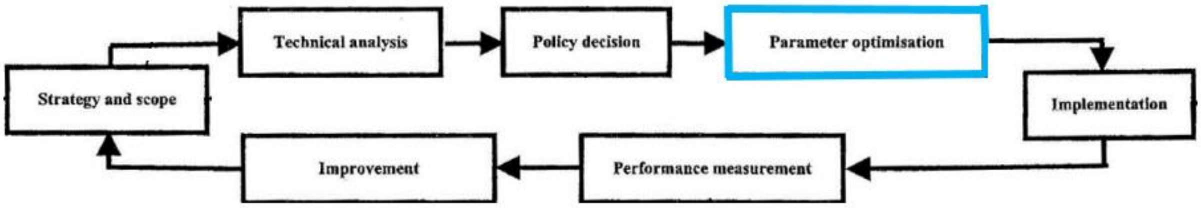


Figure 45: Maintenance concept development - part 4 (modified figure)[181]

As the maintenance policy parameters are now known, the maintenance policy parameters should be optimised. The easy implementation of time-based maintenance will be the chosen for the optimisation. Furthermore, it has the benefit that parts are changed although they are still in a good condition. This reduces breakdowns and high costs.

For the time-based maintenance there is either the age-based or the block-based maintenance. The block-based approach makes use of maintenance intervals that have to be performed after determined time intervals (*T*). However, this approach is considered to be more beneficial in case of outsourcing, as the maintenance service provider is able to group maintenance operations which saves money, whilst having to group the tasks in the best way to ensure high performance level and avoid breakdowns and changeover. The optimised maintenance is shown in tables 16 and 17.

[181] (Waeyenbergh, Pintelon, Gelders, 2001)

Table 15: Time based maintenance concept - part 1 (own depiction)

Most Important Systems	Most Critical Components	Hours of operation	Activity
Main drive	Gearmotor	2000 10000 25000	Check oil level, top off if required Change oil Change bearing grease, shaft seal and elastic rim gear
	Roller bearings or motors and gearboxes	10000 Every 2 years at the least	Change bearing grease (recommendation)
	Main bearing	1000	Lubricate
Hand Crank	Angular Gearbox	10000	Check; top off grease if required
Pulse control	Drive chains	4000	Lubricate
	Gear and chain weels	4000	Lubricate
Heating	Blower		
	Heating components		
	Main burners		
	Pilot burner	2000	Check functioning of pilot burner
Baking tong	Running wheels		
	Locking roller		
	Hook roller	15000	Check ease of movement, take down and lubricate hook rollers
	Hook bearing	5000	Check functioning, lubricate if necessary.
	Chain links	5000	Check ease of movement, lubricate via grease fitting.
	Baking tong hinges	10000	Check; top off grease if required
	Guide roller		
Chain tensioning system	Running wheels		The bearing has life lubrication and needs to be replaced, if required.
Batter deposit	Servomotor		The servomotor is maintenance-free.
	Gearbox	3000 10000	Check adapter for running noise and leaks. Check gear backlash and coupling ring, change bearing grease, change radial shaft seal.
	Roller bearings or motors and gearboxes	10000 Every 2 years at the least	Change bearing grease (recommendation)
	Batter pump	40 first 150 3000	Control: check oil level in the gearbox while the pump is at a standstill Control: check seals for leaks Control: check oil seals for leaks Control: pump pressure Oil change Oil change

Table 16: Time based maintenance concept - part 2 (own depiction)

Most Important Systems	Most Critical Components	Hours of operation	Activity
Wafer take-off device	Round belt drive		The SPIROPLAN® gear motor is maintenance-free.
	Brush drive		The SPIROPLAN® gear motor is maintenance-free.
	Roller bearings or motors and gearboxes	10000 Every 2 years at the least	Change bearing grease (recommendation)
	Round belts		Fitting new round belts or shortening of round belts that are too loose.
	Flange bearing	1000	Lubricate
	Bearing of drive axle	1000	Check; top off grease if required
	Reversing pulleys		The bearings of the reversing pulleys have life lubrication. The complete pulley needs to be replaced, if required.
Waste evacuator	Gearmotor	2000 10000 25000	Check oil level, top off if required Change oil Change bearing grease, shaft seal and elastic rim gear
	Roller bearings or motors and gearboxes	10000 Every 2 years at the least	Change bearing grease (recommendation)
	Gear and chain wheels	4000	Lubricate
	Conveying chain	4000	Lubricate
	Ball bearing		The bearings have life lubrication and need to be replaced, if required.
Exhaust gas aspiration	Exhaust blower	1800	Check, lubricate if required.

Besides the periodically maintenance of the system, optimal production should be ensured by cleaning the relevant components. For this a cleaning schedule is set. The cleaning schedule organises regular cleaning of the machine and aims to maximise the quality of the products, including aspects pertaining to hygiene standards; and to minimise production loss due to insufficient lubrication, poor adjustment etc. To ensure these benefits there is a cleaning schedule as shown in table 18.

Table 17: Cleaning concept (own depiction)

Most Important Systems	Most Critical Components	Hours of operation	Activity
Main system	General	8 40	Quick cleaning: remove loose scrap, usw compressed air, a vacuum cleaner, etc. Thorough cleaning: remove all adherent residue, use water, detergents, etc.
Batter deposit	General	8	Thoroughly clean batter depositor after the end of operation.
Heating	Infrared sensor Heating components	40 40 1000	Check position and clean lens with compressed air. Clean filter of heating and (optionally) running wheel in cooling blowers, replace filter if necessary. Clean filter mat of gas filter of heating.
Wafer take-off device	Light barriers	40	Blow-clean light barriers and reflectors with compressed air, wipe with a soft hloth if convenient.
Exhaust gas aspiration	General	1000	Check exhaust gas aspiration in general and the chamber and have it cleaned if required.

5.3.4 Feasibility analysis

The previous part considered the outsourcing of the work planning and work scheduling. The next task is to analyse, define and cluster the work execution. For this, a closer look on the implementation and execution is needed. This stage is shown in figure 45.

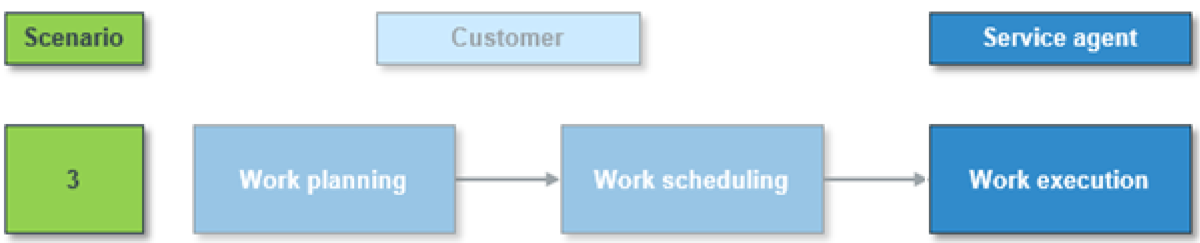


Figure 46: Outsourcing elements – part 2[182]

182 (Murthy, Jack, 2014)

The implementation shall be aligned to the suggested implementation of TPM. Before implementation is possible, it is advisable to undergo the stages of the feasibility analysis. The better the feasibility analysis, the easier the implementation later on. The introduced seven steps of the feasibility analysis by Hartmann shall be taken into account.

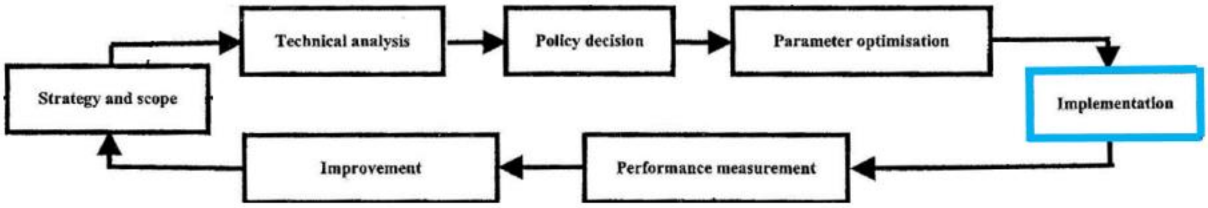


Figure 47: Maintenance concept development - part 5 (modified figure)[183]

5.3.4.1 Evaluation of temporal performance and condition of operating systems

The evaluation of the temporal performance and operation of the operating system is done with the OEE. The evaluated values can be considered as first key values, which is possible and what is the temporal situation.

The gathered information is structured and clustered by different types of data.

The failure data includes information concerning frequency and type of malfunction. The identification of the machine can be done through parameters like machine number, customer or production place. The specific time slot that is under investigation is the whole production year 2015. Here we can derive the amount of produced goods and can calculate the value created. The result of the different OEEs is shown in the following figures.

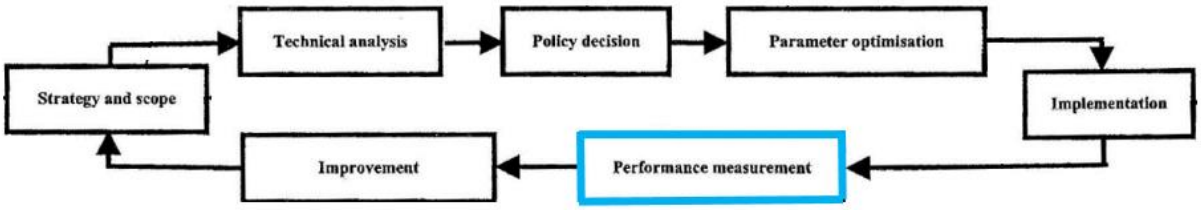


Figure 48: Maintenance concept development - part 6 (modified figure)[183]

183 (Waeyenbergh, Pintelon, Gelders, 2001)

Figure 49: OEE Line 1 – 2015 (own depiction)

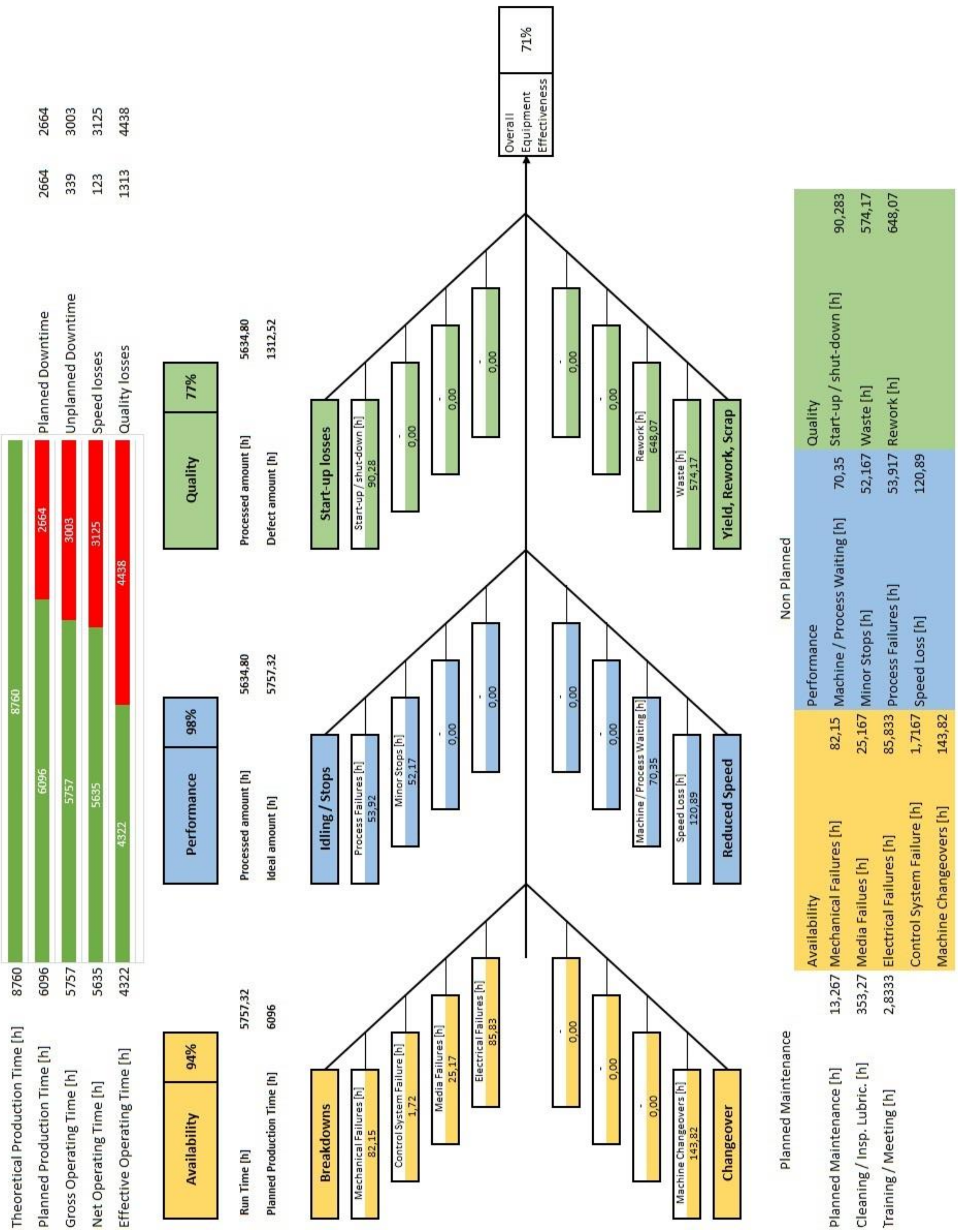


Figure 50: OEE Line 2 – 2015 (own depiction)

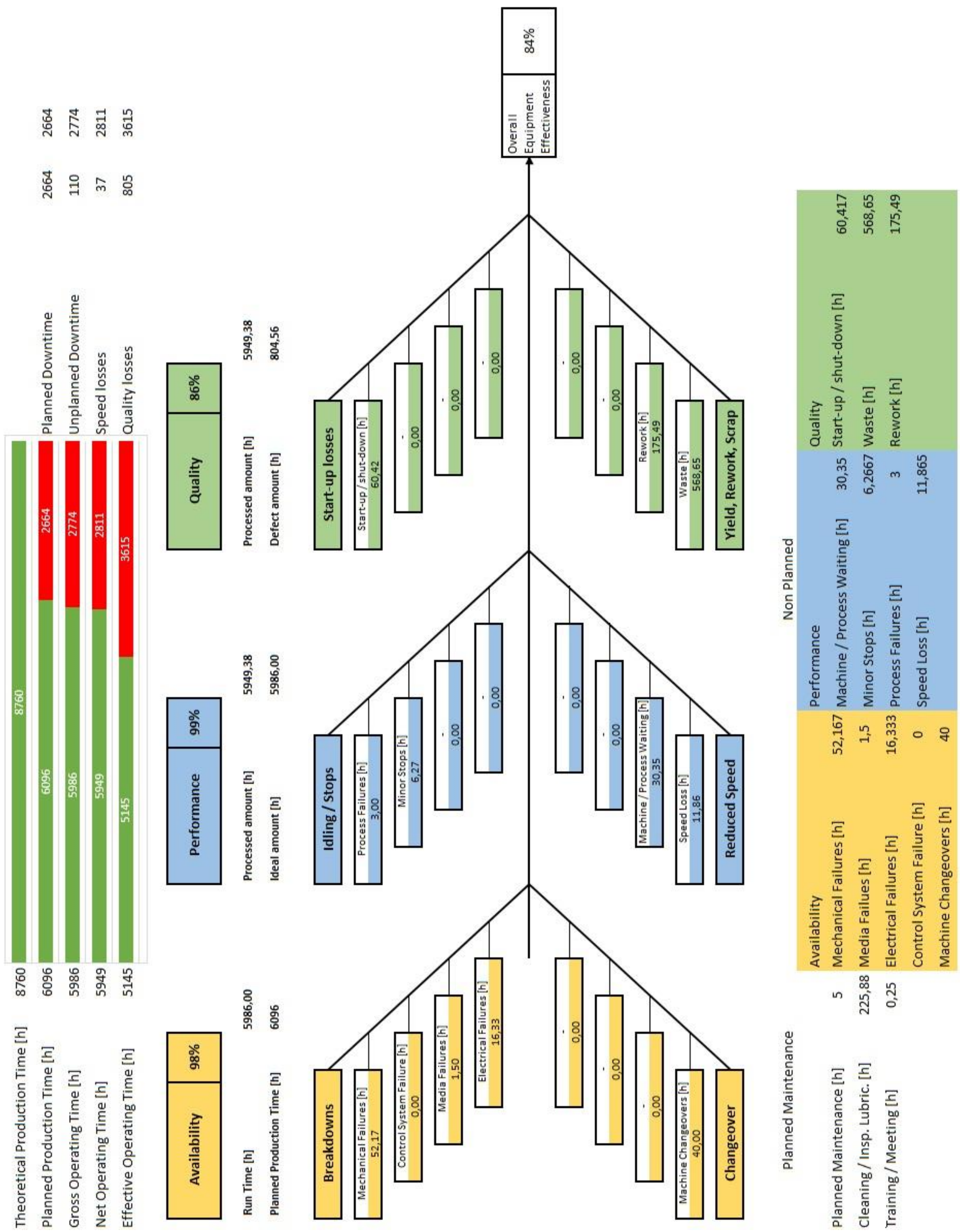
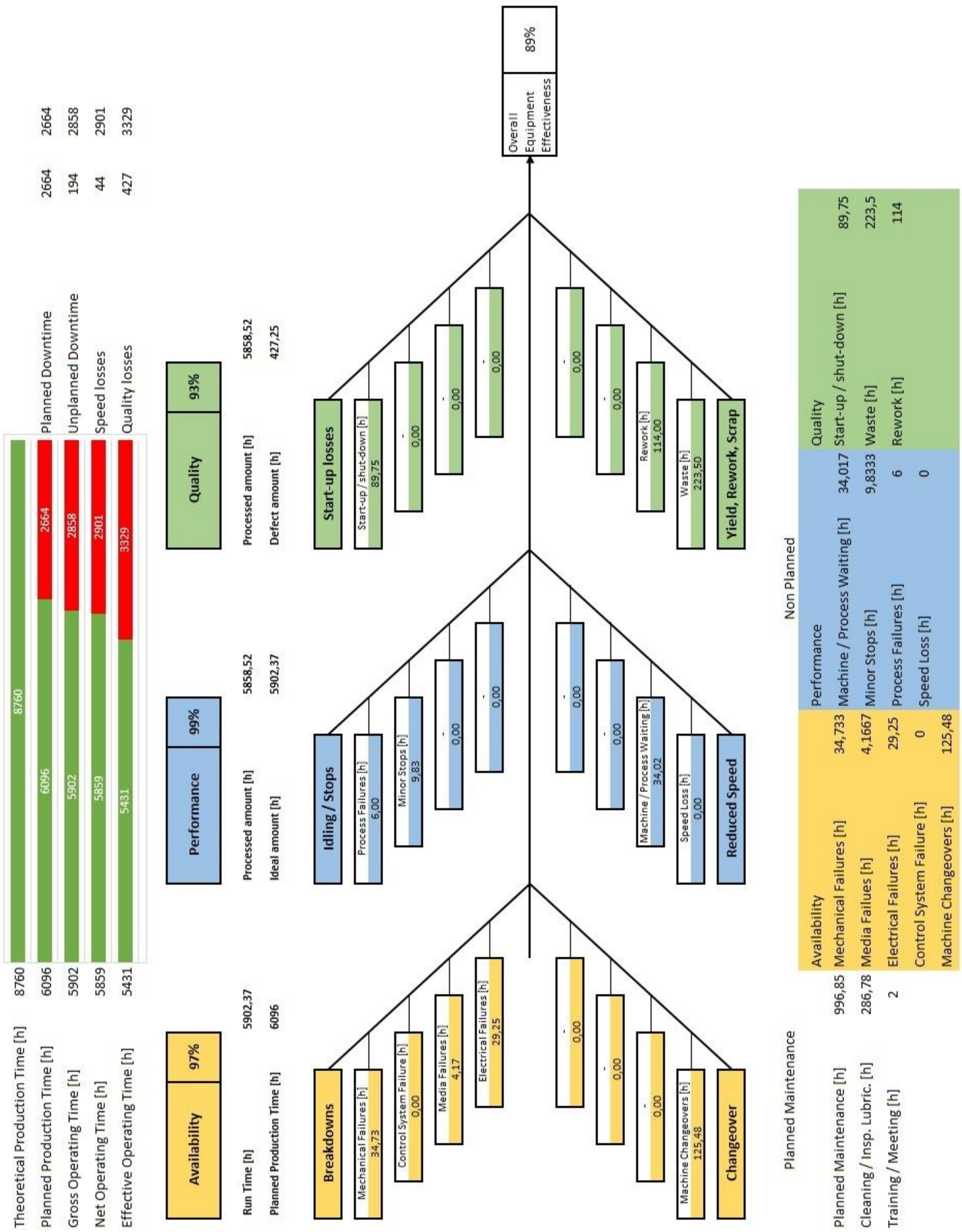


Figure 51: OEE Line 3 – 2015 (own depiction)



5.3.4.2 Evaluation of employees

The OEM should organise the amount of people and tasks that are necessary to maintain the machine. Furthermore, there needs to be a clear structure regarding who is responsible for cleaning and who is responsible for maintenance.

It is advisable that the OEM takes responsibility for the maintenance and the maintenance schedule (table 15) whilst the company is responsible for the cleaning ,(table 17) with one exception however. There is one element that needs to be checked every 40 hours of production. The control of the batter pump, in which the oil level in the gearbox during a standstill is measured. This should be part of the customer's responsibilities. This helps to reduce maintenance costs, as this activity would lead to a higher turnover of maintenance visits.

The current state is that the customer maintains the machine with its machine operators. The new plan will be that the operators will focus on their core business, operating the machine and keeping it clean and lubricated. The OEM will be responsible for maintaining the lines. To ensure constant support and intervention two new employees will be needed. The costs for the new employees must be taken into account for the maintenance service contract and have to be carried by the higher performance, which is part of the cost analysis which is discussed in the next chapter.

According to analysis concerning the amount of work for maintaining the machine, a maintenance technician is able to take care of four lines at the same time. In this case it means that there is a need for one technician per shift. As there are different shifts, holidays, weekends and vacations, an estimated number of four technicians is needed.

5.3.4.3 Evaluation of performance and results of maintenance

ThThe interpretion of the data shall help to minimise losses in the long term. For this the different lines are compared. As the investigated object is the same machine we receive a valid benchmark. By having the different values of each line we can face the assumption that it is possible to reduce the time needed for adjustment, start-up, breakdowns or mechanical errors. By comparing the theoretical OEE of each line to the actual OEE based on benchmarks, one can obtain the difference which gives the costs that result from non-optimal equipment performance.

First of all the calculated OEE's shall be compared for the recommended values, introduced in chapter 4.3.4 'Benchmarks'. There is a deviation of the recommended OEE concerning availability, performance and quality. Whilst the availability with 94%, 98%, 97% and performance with 98%, 99%, 99% is above the recommended general OEE values with 90% for availability and 95% for performance. The quality scores 77%, 86%, 93%; far below the recommended value of 99%. So the next step would be to understand the influences of the quality and set up performance indicators that help to have a positive impact on the quality. Although availability and performance can be improved as well, the highest potential is with the quality, to influence the OEE in a positive way.

After getting a general overview of possible values, a closer look shall be taken. While line 1 has an OEE of 71%, line 2 reaches an OEE of 84% and line 3 an OEE of 89%. Taking a closer look will help to understand the enormous variation of almost 20% between the three lines. For this there the average value of the results will be established. A deviation in a positive or in a negative form of the average values helps to investigate the reasons. This comparison can also be seen in the table 19.

Starting with the planned maintenance it can be seen that there is enormous variation. Line 1 and 2 have planned maintenance of only 5 to 13,27 hours a year, whilst line 3 has an amount of almost 1000 hours. Cleaning, lubrication and training do not vary between the lines.

Table 18: Comparison of the different OEE (own depiction)

	Line 1	Line 2	Line 3	Average	Recom.
Planned Maintenance					
Planned Maintenance [h]	13,27	5,00	996,85	338,37	
Cleaning / Insp. Lubric. [h]	353,27	225,88	286,78	288,64	
Training / Meeting [h]	2,83	0,25	2,00	1,69	
Non Planned					
Availability	94%	98%	97%	96%	90%
Breakdowns	194,87	70,00	68,15	111,01	
Mechanical Failures [h]	82,15	52,17	34,73	56,35	
Control System Failure [h]	1,72	0,00	0,00	0,57	
Media Failures [h]	25,17	1,50	4,17	10,28	
Electrical Failures [h]	85,83	16,33	29,25	43,80	
Changeovers	143,82	40,00	125,48	103,10	
Machine Changeovers [h]	143,82	40,00	125,48	103,10	
Performance	98%	99%	99%	99%	95%
Idling / Stops	106,09	9,27	15,83	43,73	
Process Failures [h]	53,92	3,00	6,00	20,97	
Minor Stops [h]	52,17	6,27	9,83	22,76	
Reduced Speed	191,24	42,21	34,02	89,16	
Speed Loss [h]	120,89	11,86	0,00	44,25	
Machine / Process Waiting [h]	70,35	30,35	34,02	44,91	
Quality	77%	86%	93%	85%	99%
Start-up losses	90,28	60,42	89,75	80,15	
Start-up / shut-down [h]	90,28	60,42	89,75	80,15	
Yield, Rework, Scrap	1222,24	744,14	337,50	767,96	
Waste [h]	574,17	568,65	223,50	455,44	
Rework [h]	648,07	175,49	114,00	312,52	
OEE	**71%**	**84%**	**89%**	**81,41%**	**85%**

Temporarily the highest time loss in the case study happens in the quality section. Waste and rework make the production inefficient. This results in unnecessary losses. The question arises how to improve the quality and what causes the impact. However, it is obvious that the line with the highest amount of planned maintenance has the highest output of quality and least amount of waste and rework.

5.3.4.4 Evaluation of the cleaning condition

To evaluate the cleaning condition and guarantee a high quality through disciple the 5S concept has been introduced already. The average time taken for cleaning and lubrication is approximately one hour per working day. This work task can be covered by the former maintenance staff which now has less obligations, as the tasks are no longer fulfilled by the maintenance provider. However, the 5S concept is not applied yet. To be able to detect oil leakages quicker it helps to work in a clean environment. This and many other reasons make the method 5S necessary for a successful maintenance concept.

The implementation consist of four main parts.

Plan	Set up a 5S council that consist of at least one person of the service providing company
	Set up 5S Zones in the company
	Determine objectives, goals, action plan for each 5S phase and the launch
	Prepare trainings and education for the employees, so that they identify with 5S
Do	Fulfil the described actions from the planned action plan
Check	Set standards for cleaning conditions
	Have audits to get an overview of how 5S is running
	Set up benchmarks within the department
	Visualise the cleanliness of each zone quick and simple
Act	Compares of defined and actual goals
	Reward employees who commit to 5S mentality

5.3.5.5 Elaborate upon costs, profit and return on investment

This step is needed if the top management has to be convinced of the new maintenance concept. For this a comparison of costs and profit is needed. The costs for both parties need to be taken into account, as it can be assumed that the customer offers the outsourcing just in case it is beneficial, while the OEM offers the maintenance service only in the case that it has a return on investments. The calculation is based on the data set of the year 2015.

Derived from the maintenance concept it is assumed that each planned maintenance activity takes 24 hours. This is estimated twice a year and done during the weekend, as the machine has to be maintained during a stand still. Furthermore, it is assumed that a total of 24 unplanned, corrective maintenance activities are completed over the year. It is considered that the average time for one corrective maintenance case takes two hours.

Customer

To identify the costs for customer the following data is needed. As the maintenance concept aims to increase the performance, the costs for production have to be taken into account as well. This means primary, secondary and tertiary resources. Besides this, the maintenance costs and costs for spare parts also have to be part of the calculation. The costs for the customer are depicted in the tables 20-23.

As the productivity increases, the required raw materials increase. This influences the costs as well. Although the estimated costs are similar to the real estate, it must be taken into account, that the amount of produced goods increases. Comparing the accumulated production of the three lines to the estimated one, leads to a possible increase of the gross margin from: €12.348.054 to €12.847.464, which is a difference of €499.410 in total. This has to be compared to the new estimated costs, which would be reduced to €31.147 as the cost decrease from €10.323.415 to €10.292.268.

In total the gross margin would increase by €499.410 and the costs would decrease by €31.147 which makes a total change in the earnings before incoming taxes of €530.557. The comparison can be seen in figure 52.

Table 19: Costs for customer (own depiction)

General Data	
How many hours per day will the wafer production line be in operation?	24h / day
How many days per year will the wafer production line be in operation?	254 days / a
How much does the square meter cost per month in EUR?	4,50 € / month
What is the average net wholesale price per kg product in EUR?	8,00 € / kg
Labour Costs	
What is the hourly salary for one operator in EUR at full cost?	10,00 € / h
What is the hourly salary for one maintenance technician in EUR at full cost?	15,00 € / h
Energy Costs	
Do you use Liquid Petroleum Gas (LPG) or Liquid Natural Gas (LNG)?	LPG
What does liquid gas (LPG) cost per kg in EUR?	0,27 / kg
What does electricity cost per kWh in EUR?	0,07 € / kWh
What does compressed air cost per m³ in EUR?	0,05 € / m³
Raw Material Costs	
Wafer Batter: What does flour costs per kg in EUR?	0,61 € / kg
Wafer Batter: What are the costs for fat, oil and other ingredients per kg in EUR?	1,75 € / kg
Line Specifications	
Number of baking plates per line	88
Baking plate width in mm	350 mm
Baking plate length in mm	500 mm
Average weight per wafer sheet in g	65,00 g/sheet
Average baking time of the oven in min	2,00 min
Energy consumption, labour & space requirements	
Liquid gas consumption per oven ber kg wafer sheet (kg LPG/kg wafer sheet)	0,22
Electricity consumption in kW/h	70,00 kW / h
Compressed air consumption in m³/h	70 m³ / h
How many m² space be required in total?	230,0 m²
How many operators will be needed in total?	3

Table 20: Costs for customer - Line 1 (own depiction)

Line availability and efficiency	
What is the line availability in percent?	94 %
What is the line performance in percent?	98 %
What is the baking waste in percent?	21,7 %
What is the cutting waste in percent?	5 %
Maintenance	
How many man hours per year, per line, do you spend for maintenance?	211 h
How much is the spending for spare parts and consumables (grease, oil) per year, per line in EUR?	17400 €

Table 21: Costs for customer - Line 2 (own depiction)

Line availability and efficiency	
What is the line availability in percent?	98 %
What is the line performance in percent?	99 %
What is the baking waste in percent?	12,5 %
What is the cutting waste in percent?	5 %
Maintenance	
How many man hours per year, per line, do you spend for maintenance?	80 h
How much is the spending for spare parts and consumables (grease, oil) per year, per line in EUR?	15200 €

Table 22: Costs for customer - Line 3 (own depiction)

Line availability and efficiency	
What is the line availability in percent?	97 %
What is the line performance in percent?	99 %
What is the baking waste in percent?	12,5 %
What is the cutting waste in percent?	5 %
Maintenance	
How many man hours per year, per line, do you spend for maintenance?	1064 h
How much is the spending for spare parts and consumables (grease, oil) per year, per line in EUR?	12400 €

	Line 1	Line 2	Line 3	Estimated
Total production volume p.a.	915,5	964,2	954,3	964,2
Total production volume for 1 years	915,5	964,2	954,3	964,2
Raw Material Costs	0,99	0,88	0,88	0,90
Labour Costs	0,20	0,19	0,19	0,19
Energy Costs	0,11	0,11	0,11	0,11
Maintenance Costs	0,02	0,02	0,03	0,00
Operating Costs per kg finished product	1,32	1,20	1,21	1,21
Fixed Costs per kg finished product	2,48	2,35	2,38	2,35
Total Costs per hour	570,8	561,2	561,5	562,8
Total Costs per year	3.479.346	3.421.223	3.422.846	3.430.756
Total Costs per kg product	3,80	3,55	3,59	3,56
Gross Margin per kg product	4,20	4,45	4,41	4,44
Total Gross Margin p.a.	3.844.341	4.292.021	4.211.692	4.282.488

Figure 52: Total gross margin for customer (own depiction)

OEM

The OEM has to ensure the production of the three lines. For this it is estimated that there is a need of a technician in every shift. Furthermore, there are planned maintenance activities depending on the maintenance concept, developed in the chapters before. The assumptions for planned maintenance activities can be seen in chapter 4.6.1 'Assumptions'. Furthermore, the spending for spare parts is reduced by the half. As the OEM is manufacturing the spare parts itself it has cheaper prices per spare part than the customer. The depiction of costs for the OEM is shown in table 24.

Table 23: Costs for OEM (own depiction)

General Data	
How many hours per day will the wafer production line be in operation?	24 hours / day
How many days per year will the wafer production line be in operation?	254 days / a
Labour Costs	
What is the hourly salary for one maintenance technician in EUR at full cost?	15,00 €
How many maintenance technicians are needed per line?	0,25
Maintenance	
How much is the spending for spare parts and consumables (grease, oil) per year, per line in EUR?	22.500 €

The estimated costs are calculated for one year for the OEM.

Labour cost for the maintenance service	92.500 €
Spare parts (multiplier of 0,5 as there is no intermediary)	22.500 €
Costs for trainings, materials and equipment are	20.000 €
Which makes a total of	135.020 €

By dividing the profit of the customer with the costs of the OEM, we receive the return on investment which would be: 530.557 € / 135.020 € = 3,93

5.3.5 Implementation and Organisation

The implementation consists of three different stages:

1. Planning and preparation of the installation
2. Pilot installation
3. Plantwide installation

In the case of this work and the preparation for the concept, the focus will be set on the planning and preparation of the installation. Following this, the focus will move onto the elements which the service provider can influence.

5.3.5.1 Planning and preparation of the installation

1. Develop an installation strategy

This step is used to order the actions. The focus is on the maintenance service provider. For this, the equipment management (EM) will be considered first and later on preventive maintenance (PM). As the optimisation of EM leads to quick benefits in the OEE, the producing company can gain trust in the experience of the service providing company, which helps to show the benefit of the outsourcing.

As it is easier to implement a maintenance concept in one area of the company it is also easier to implement the provided maintenance service first at one machine, to gain experience and trust in the process. This could be, as suggested above, a bottleneck machine, to increase the productivity of the whole plant. In this case it is the Line 1, as this Line has the highest potential to increase productivity.

2. Develop and implement an organisation structure

Similarly to TPM, in companies it is suggested to name the responsible employees. The first question is who is the responsible employee who coordinates the TPM in the organisation and with a representative of the producing company. Such as is the case with regular TPM set ups, it is suggested to name an engineer or an employee with experience in maintenance and the equipment. As the case considers only a pilot installation there are no plans concerning a TPM committee yet that reports to the top management directly. For this the responsible person will be the maintaining technician, who reports to the OEM directly and is in direct contact with the customer.

As soon as the decision was made to undertake maintenance service, the service technicians need to be trained in working with the customer and the extended responsibility. Furthermore, it has to be checked to whether there is a need for new employees and the training thereof.

3. Develop a vision, strategy and policy

The vision takes usually a long-term perspective of five to ten years. The vision, strategy and policy must be aligned the companies strategy. As the service provider has its own service department the strategy shall be taken into account that is helping to reach the department's vision. However, the policy is important for the producing company. As employees might fear the upcoming change and the outsourcing, the whole process needs to be communicated and the employees should be part of this process so to avoid fears and mistrust. Questions for this should be faced and answered already before communicating the idea.

4. Develop the goals

As suggested above the feasibility analysis can be taken to consider appropriate goals. Especially the current OEE is a suitable tool. Depending on forecasting of the state-of-the art research, the breakdown time could be reduced due to maintenance outsourcing of an average of 15%.

In the investigated cases, the main potential for improvement is the quality.. The overall goal would be to increase the OEE in all lines to a value of 85% or keep up the value of 89% of line 3, in the next two years. This would increase the productivity from an accumulated 14898 hours to 15794 production hours, or increase the total productivity by 6%. A more detailed plan is listed below.

Goals for the top management:

- Reduction of total cost by 10 % by outsourcing maintenance
- Increase productivity by 5 %

Goals of the middle management are:

- Increasing the OEE from 71 % to 85 % respectively keep it at 89 %
- Increasing the quality to 90 %

Operating goals would be:

- Reducing the baking waste to 15 %

5. Trainings

There are two trainings that have to be distinguished. On the one hand there are the trainings for the customer and its employees. On the other hand there are the maintainer of the OEM, who fulfill the maintenance service activities.

The customer is responsible for lubrication and keeping the work space tidy and clean. For this the 5S stages need to be taught and implemented.

Whilst, the customer is responsible for the lubrication and the surrounding, the OEM needs to train his own employees in terms of maintenance. For this the above mentioned maintenance activities need to be taught to the maintainer.

6. Perform PR

The next step would be to make the concept more public. Publishing the idea of the outsourcing and the concept in the company would be the next step. As it is considered for SMEs it is assumed that there is no intranet. The idea could be published by a work newsletter, weekly meetings, a business meeting or posters and black boards. As the topic is about outsourcing activities, the idea might cause some fears within the workforce. For this it is advised to communicate the changes directly. It is strongly recommend to add the information, that it is not about reducing personal capacity. The people who were responsible for maintaining the machines can now focus on lubricating and operating the machine.

7. Develop a whole plan for the concept

After getting an overview of the activities that are needed to reach the admired goals, worked out together in stage four. The first part would be to define the chronology of the implementation, EM, PM, how much time it takes and where in the company or at which machine it will be implemented first. As it is not possible to plan all this already without any practical experience it helps to get an overview of all the tasks that have to be done until the concept is implemented in the whole company. After the first installation, the pilot installation, there is a better know how about the implementation and the schedule can be adjusted. For this it is not necessary to plan every detail of the whole plan, as it is not possible yet to assume the time needed for each element. This leads to the element of the plan development of the pilot installation.

8. Develop plan for pilot installation

The pilot installation is crucial for the success of TPM and thus for the success of the outsourced maintenance service.

As the implementation starts with EM, the focus is on equipment management. The maintainer needs proper training to be able to undertake problem analysis and find solutions for upcoming problems. Furthermore, the machine that the pilot installation is set on is first completely overhauled. The condition of the machine can then be considered as new and there is no uncertainty concerning knowledge of data or parts. Every error or break down that occurs can be taken down and considered for future maintenance plans or adjustments.

The pilot installation takes place on Line 1, which has an OEE of 71% and the highest potential for improvement. The increase of an OEE at Line 1 is easier than increasing the OEE of Line 3, which has an OEE of 89%. This helps to generate quick success and strengthen the relationship between the customer and the OEM.

9. Develop detailed plans for further installations

As soon as the first installation is in progress, there is information about the process and its duration. This data will be used to set more precise planning for the further installation.

10. Presenting to management

Before starting with the first installation of the pilot TPM the management needs to agree with it. For this the actual data and the plan will be presented to the management of the OEM and the customer, who need to confirm the approval of the next step, the pilot installation.

5.3.5.2 Pilot installation

The pilot installation is the first installation of the outsourced maintenance in the company. As there is no experience of it yet, the focus is on a machine or a division where good prepared data for the feasibility analysis was available. This would be respectable for lines one, two and three. Choosing a division with high motivation for better maintenance supports the process as well. Besides these factors, the size of the division has an important role as well. The bigger the division the more difficult to keep an overview. As each line has three employees per shift at work there is no problem in dealing with more than 50 or 100 employees. Furthermore, the concept concerns SMEs so this problem be reduced.

The idea of the pilot installation is to gain preliminary information and put some elements to the test. It is not possible to finish the outsourced maintenance service in the pilot installation before implementing it to other machines or divisions. As this would take two to three years. It is more about trial and error and learning from mistakes before adapting this to other parts of the company. This means the pilot installation has a time frame of approximately three months ahead of the two lines.

However, the pilot installation does require working groups. The setup should consider the information of the feasibility analysis. In the following steps the installation of the three elements EM, PM and AM will be introduced separately.

1. Installation of EM

2. Installation of PM

3. Installation of AM

1. In most of the companies the TPM-EM is being implemented first. The collected data in the feasibility analysis provides the EM installation with information. As it is difficult to say where to start, the OEE can be taken and analysed. As advised, the equipment with the highest losses should be considered as the first elements to be optimised.

The optimisation process can consist of different steps, depending on the size of the production line. As the production line consists of only one line, the OEE can be taken into account.

As it is considered to do a general overhaul, it can be assumed that the machine is in mint condition. If a problem or an error occurs, the origin of this problem needs to be found and the source for it has to be clarified. The challenge is to remove the origin of the problem and not prevent it by quick maintenance. The suggestions and solutions of the maintainer are collected and carried out on the equipment. Following significant changes to the machine or the equipment, a new OEE of the machine should be made. A tool to avoid losing the overview is the OEE improvement check list. The list contains actions and machine losses and helps the team in considering each element. For this, table 6 should made use of, as it contains the important influences for each element.

2. To avoid equipment malfunction and keep it in a good condition, PM is the best option. The developed maintenance concept is taken into account to guarantee a good production process and reduce the risk of break downs. In order to guarantee successful production the machines need planned downtimes. However, the time that is needed for a good PM is, compared to a malfunction, far less and will convince the production manager to undertake PM.

3.) As the 5S concept is considered to be part of the maintenance service contract, the clean surroundings of the machine can be considered already; keeping in mind that it is more motivating to keep a clean machine tidy than a dirty one. The next logical step would be to check the machine for abrasion and wear. Typical parts are tubing connections, components, security items and other parts. Collecting the parts that have to be cleaned helps to keep the check list up to date and gather information. However, it is important that the employees have the necessary skills to clean the parts and assemble the machine properly again. However, the 5S concept shall be extended by the seven steps developed by the Japanese Institute of Plant Maintenance (JIPM), mentioned in chapter, 4.3.2 'Pilot installation of TPM'. Although it has been mentioned already, these steps shall be recalled briefly.

A) Basic cleaning

- Recognise small problems before they become serious.

B) Countermeasures in the source of problems

- Keeping a machine clean is better than cleaning it.

C) Definition of cleaning and lubrication standards

- Cleaning and lubrication standards have to be easy and non-bureaucratic.

D) Implementing a general inspection

- Maintainers and operators understand their machine the best.

E) Autonomous inspection (for defining the new standards, the following questions should be asked)

- Where is an action needed?
- What is the condition, that shall be reached with the action?
- Which method is used to reach the condition?
- Which tool, knowledge or skills is needed?
- How much time does the action take?
- In which periodic intervals does the action has to take place?
- Who is responsible?

F) Organisation and order

Extend activities to the whole surrounding.

G) Complete autonomous operator maintenance

Set up a continuous improvement process.

5.3.6 Improvement

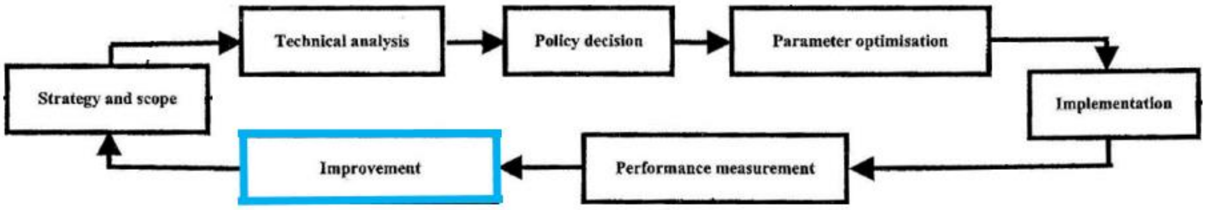


Figure 53: Maintenance concept development - part 7 (modified figure)[184]

The improvement is extended to a continuous improvement process. First, the mentioned improvements are done in this part. More specifically the implementation and improvement of the quality. The actions have to be measured and evaluated in terms of efficiency and effectiveness. However, the whole process starts all over again and keeps continuously improving. This means, that after the corrections the maintenance service with planning, preparing and performing starts all over again. In the case study the improvement starts with the improvement of the OEE and implementation of the above mentioned continuous and planned maintenance concept.

The quality in wafer production is a more complex process. It is dependent on different parameters. Parameters like the shape of the wafer, the viscosity, the baking temperature and other process parameters. The task is to find the key influences on the quality and how to measure it to improve the quality simply and quickly.

Analysis of technical development have shown that the quality is highly dependent on the viscosity, the moisture, the thickness and the weight of the wafer sheet. Everything else can be adjusted to these parameters. The challenge is that the viscosity is not only dependent on the mixture of the ingredients. It is also dependent on the air humidity and the supplier of the ingredients, as the flour varies in the quality as well. By analysing the viscosity of the dough, the company can adjust the amount of pressure they have in their pipes that spread the dough on the baking plates. For this a standardised quality measurement plan is needed to ensure high quality. This plan has the demands to be understood easily and to be able to process the measurements quickly and simply. The developed plan is shown in chapter 9.3 'Annex – Measurement Plan'. It consists of different main topics:

1. Viscosity

Depending on the viscosity the parameters for the dough pourer have to be adjusted. As mentioned above, the viscosity is dependent on many external influences like

[184] (Waeyenbergh, Pintelon, Gelders, 2001)

humidity, air pressure and air in the dough. To ensure valid measurements, it is advised to do the measurement in working conditions close to the dough pourer.

The viscosity is measured with a 100ml flow cup and the time that is needed to see the whole again is taken. To avoid mistakes the measurement is to be repeated ten times. Depending on the average value it must be possible to set the parameters of the dough pourer. If the values are extending the tolerance set by the company, the dough should be remixed or thrown away. The more constant the measurements are, the easier it is to set the parameters like pressure and rotations per minute of the pump. A deviation should be set in percentage.

2. Moisture

The moisture of a wafer sheet is responsible if a wafer sheet is burned and brown or only lightly coloured. The condition depends on the customer.

The measurement of the residual moisture can be done by a Halogen-moisture measurement of the wafer sheet. For this, the wafer sheet has to be shredded to tiny pieces and then be put inside the moisture measurement system. The measurement takes an approximate time of three to five minutes and takes the weight difference before and after the measurement. The difference helps to set the percentage of water inside the wafer sheet. The result should be less than two percent, as a value above two percent is an indicator that the wafer is still raw inside.

3. Thickness of wafer sheet

The thickness of the wafer sheet is dependent on the baking plates. The producing company guarantees deviations less than 0,1 mm. The thickness influences the baking time and the moisture. For this, a reliability in this is crucial. To ensure a fluent production, the thickness has to be measured at each baking plate at three positions. At the hunge side, the centre and the lock side of the plate. The average value and the deviation of max. 0,1% helps to evaluate the baking plate and its influencing factors. This procedure has to be done for each baking plate of the machine, which can be up to 120 plates.

4. Weight of wafer sheet

The final element of the quality is the weight of the wafer. A wafer sheet with a certain amount of ingredients, thickness and moisture should have a certain value. If there are deviations the wafer cannot be sold. For this, the weight of ten wafer sheets is being take and compared with known values. If there are no deviations extending the tolerance, the wafer can be sold.

If there are deviations in the measurement check list, the dough has to be adjusted and cannot be used for the production. This avoids hours of rework and scrap and ensures higher quality in the production.

5.3.7 Plantwide installation of the concept

The pilot installation helps to understand how the employees react to different methods. Approximately three months after the start of the pilot installation it is possible to apply the learned lessons to the other lines. Based on the new information the line further implementation of outsourced maintenance can be adjusted and prepared in more detail. The maintenance service contract can be extended to the other lines.

6 Discussion and Outlook

The goal was to provide a service maintenance concept for SMEs based on TPM and its corresponding KPI – OEE. Furthermore, different question needed to be answered to ensure the set up and implementation of the service maintenance concept.

- **Q1:** How to set up a maintenance concept?
- **Q2:** How to implement and organise the maintenance concept?
- **Q3:** How to measure the performance of the maintenance concept?
- **Q4:** What is the overall equipment effectiveness (OEE)?

In the following, the results and the methodology are discussed and a conclusion is drawn. Afterwards an outlook and future research are both outlined.

6.1 Results

Research showed that there are several maintenance concepts available in the literature. However, among the analysed concepts, the so called pro active maintenance conceot is the only one considering dofferent outsourcing scenarios. These concepts were not applied to different outsourcing scenarios. However, this concept considers outsourcing of maintenance for SMEs. In regards to the so called proactive maintenance: The benefits and tasks hereof and also the single elements of the maintenance strategy, the KPI and the development of a maintenance framework concept is compared in table 25. The comparison shows that it is necessary to expand the original concepts with some tools to be able to set up a service maintenance concept for SMEs. The concept is based on TPM, as TPM and its KPI – OEE. As it covers most of the demands of a performance indicator.

Furthermore, the application of the concept proved its simplicity. This is important for SMEs, as they need to understand and support the process. It is also important that the concept has quick benefits to show the reliability. The use of the original TPM strategy helps to gain quick benefits and also an increase of the long-term effectiveness. This can be done by optimising the equipment first which leads to the quick success.

Table 24: Comparism of different concepts (own depiction)

Task	Maintenance Framework concept	TPM	OEE	Design for Maintenance	Pro active Maintenance	New Concept
Outsourcing scenarios	-	-	-	-	-	+
Work planning	+	+	-	-	+	+
Work scheduling	+	+	-	-	+	+
Work execution	-	+	-	-	+	+
Maintenance Concept	+	-	-	-	-	+
Maintenance Strategy	-	+	-	-	+	+
Implementation	-	+	-	-	-	+
Causes and Effect	-	-	+	+	-	+
Possible Solution	-	-	-	+	-	+
Part redesign	-	-	-	+	-	+
Performance measurement	-	-	+	-	+	+
Continous Improvement Process according EN	-	-	-	-	+	+
Short-term increasing of efficiency	-	+	+	-	-	+
Long-term increasing of effectiveness	+	+	+	+	+	+

The arrangement of the concept is carried out in different steps. It starts with the strategy and scope in which the SME decides upon the outsourcing scenario. The scenario describes which parts of maintenance are being outsources. It is possible to outsource the following:

- the work planning - Which components need to be maintained
- the work scheduling - When is it necessary to carry out the maintenance
- the work execution - How to carry out the maintenance

Dependant on this, the concept can be either more or less complex. However, literature advises for SMEs to outsource whole activities. For this, the following description is considers the outsourcing of all maintenance activities. After the strategy and scope, the step for work planning has to be addressed, the technical analysis. The analysis checks the most important systems and identifies the most critical components, before in the policy decision it is decided how the different components are being maintained. In the next step the implementation of the decisions is done. First the installation is planned and prepared, before it is installed at a pilot machine or line and finally plant-wide. The performance measurement is done with the OEE, which is one of the most important effective KPIs in performance measurement. This is crucial for the improvement as in this stage the changes are implemented and you need to be able to track the performance before and after the implementation. Finally, the whole process continues to repeat itself.

Although, more than 100 SMEs have been taken into account for the study, there was only one company that collected the data in such a detailed way that was possible to set up an OEE. The survey of the customers shows that the SMEs in the wafer bakery branch are either not aware of the high potential of maintenance or do not want to share their information. This assumption is based on the fact that there is hardly any collection of data concerning breakdowns, changeovers, idling, yields and waste or rework. All these key figures are part of the OEE which is part of TPM, which has been developed 30 years ago. However, based on literature fact it can be assumed that companies are willing to share their information if there is a benefit for them. For this the conclusion is made that most of the questioned SMEs companies do not collect data or at least data in a sufficient way to be able to interpret the information and derive necessary maintenance tasks. Besides the need of a maintenance concept for SMEs, the results have shown that in our case study the company has issues to fulfil certain quality standards during the production which leads to a comparably low OEE. The OEE and it parameters varies between the different investigated lines.

Whilst an availability of 94%, 98%, 97% and performance of 98%, 99%, 99% is above the recommended general OEE values with 90% for availability and 95% for performance, the quality is at 77%, 86%, 93% far below the recommended value of 99%. After getting a general overview of possible values, a closer look is taken on the OEE. While line 1 has an OEE of 71%, line 2 reaches an OEE of 84% and line 3 an OEE of 89%. The planned maintenance has enormous variation. Whilst line 1 and 2 have a planned maintenance of only 5 to 13,27 hours per year, line 3 has an amount of almost 1000 hours. Cleaning, lubrication and training do not vary between the lines. However, the line with the highest amount of planned maintenance has the highest output of quality and least amount of waste and rework.

The results show that there are no standards in the planned maintenance for the lines within the investigated SME. Whilst one line has almost 1000 hours of planned maintenance activities and a comparatively high output, the maintenance of the other lines is hardly maintained by planned maintenance.

Although the provided data by the investigated SME lead to the assumption that it is a company with a fundamental maintenance concept, that understood the importance of maintenance and OEE, the enormous deviations in planned maintenance activities between the lines do not support this assumption. However, similar to results of other scientists, mentioned above, the cost analysis and the OEE of the case study show that it is beneficial for SMEs, if they makes use of a service maintenance concept provided by the OEM or other maintenance service provide.

6.2 Discussion

The development of the service maintenance concept is based on the framework for maintenance concept development from Wayenberg and Pintelon which has the following order: Strategy and scope (1) → Technical analysis (2) → Policy decision (3) → Parameter optimisation (4) → Implementation (5) → Performance measurement (6) → Improvement (7). Simultaneously another service maintenance concept for outsourcing of maintenance has been considered. Based on the findings, a new service maintenance concept based on TPM and its KPI OEE has been developed.

The *strategy and scope (1)* leads the direction of the maintenance concept. The developed concept focuses on the outsourcing of the maintenance activities of one machine line. In the *technical analysis (2)* data is collected that is necessary for the *policy decision (3)*. Based on the collected data and aligned to a maintenance decision tree, the optimal maintenance concept for the critical components and each belonging part is set up. The maintenance tasks of the components and tasks is clustered in the *parameter optimisation (4)*, before the new designed maintenance concept is being implemented. The *implementation (5)* is done with the feasibility analysis and implementation concept of TPM. Further, the *performance measurement (6)* is done with the OEE which is the KPI of TPM. Derived from the OEE and the availability, and the performance and quality, different improvement activities can be planned. The implementation of the planned activities is part of the *improvement (7)* before the whole process starts all over again.

The actual approach is based on proven scientific methods. However, the critical reflection of the chosen solution leads to an improvement of the approach.

- TPM-AM: the TPM approach has two types of strategies. It can either aim to optimise the maintenance process or to transfer as many tasks as possible from the maintainer to the operator. The transfer of responsibility is described as part of the autonomous maintenance.

- TPM-PM: the developed concept is based on data which was collected by employees by writing down idling, break downs, broken parts etc. The use of for example bar codes and the automised collection of data is one possibility. Further, the concept focuses on a control report, how accurately the maintenance and performance is working. An interim report is about the benefits and progress of planned maintenance which has not been considered yet.

- TPM-EM: the OEE and error sheet were used to analyse potential improvement of the current performance. However, what is not considered yet is a logbook with information concerning the following:
    - What happened and how often? – Description of incidents

- Why did it happen? – According your opinion, why did the mistake occur
- What can be done against it? – How to avoid similar incidents in the future

- OEE: Although the OEE is one of the most important effective KPIs in performance measurement, there are other KPIs that measure maintenance performance as well. It is important for an optimal production quantity to have an appropriate maintenance and safety strategy. Other important measures for this are:
  - Total cost of maintenance/total production cost;
  - Mean time to repair (MTTR) = sum of total repair time/number of breakdowns;
  - Mean time between failure (MTBF) = number of operating hour/number of breakdowns;
  - Maintenance breakdown severity = cost of breakdown repair/number of breakdown;
  - Maintenance improvement = total maintenance man hours on preventive maintenance jobs ÷ total man hours available;
  - Maintenance cost per hour = total maintenance cost/total maintenance man hours;
  - Man power utilisation = wrench time/total time;
  - Manpower efficiency = time taken/planned time;
  - Material usage/work order = total material cost/number of work order; and
  - Maintenance cost index = total maintenance cost/total production cost.
- Smart maintenance: it is no longer sufficient to collect the data from different sources. The data has to be connected and processed. It can be concluded that a company that wants to work in the industrial revolution of the internet of things needs to adjust the maintenance system to a smart factory. The temporal concept is not considering this element yet

- LSM: The value added contribution can either be the maximum principle or by the minimum principle and the decrease of maintenance costs. The concept has so far been focusing only on the increase of outcome/output and not on the decrease of maintenance costs. Further, the weak point analysis helps to identify deviations and sets a fundament for adjustments. The weak point analysis focuses on two parts. One part is the analysis of the maintenance and preventive maintenance methods concerning their effect, risk, reliability and losses and takes the OEE into account. The second part includes the infrastructure and the environment that have also an influence on the maintenance strategy. The concept considered only the first part yet and excluded the second part, the infrastructure, and the environment completely. LSM consists of two paths, the lean patch and the smart path. The smart path is data driven and has not yet been considered. The IoT suggests possible solutions in this field.

- IoT: Tools like cameras, sensors and actuators and an embedded software allow to generate, collect and analyse data during the operation of a machine. The Internet of Things allows then that the machine is not just sending the information all around the world, it is more enabling communication between the different devices. Manufacturers and operators of big machines manage and observe their devices over long distances. The responsible persons should be informed in a timely manner if there are problems arising. This would help to support the preventive maintenance and to evaluate different actions to avoid a problem coming up. The first step to be able to maintain machines over long distances (also called remote maintenance) is to create an infrastructure of connectivity and digitalisation. This has to be considered in further investigation. Especially the challenge, that for SMEs it is not possible to create a new production environment and buy a new plant. It is more important to make use of the available equipment and adjust it to be able to make use of all the benefits of the IoT. However, the concept helps to define all the necessary objects that influence the parameters. The collection of the data and process the information of the crucial objects while it is collected is from fundamental importance. These tasks need to be automated without any interruption. Furthermore, only one key parameter that supports the transparency, consistency, reliability and topicality of the OEE has been considered. Other parameters like:
    - run through time
    - cycle time
    - setup time
    - layover

    - inventory
    - quality
    - adherence to schedules
    - productivity
    - security
    - need to be taken into account as well.

- MSC: Different maintenance service contracts exists; work package, performance and facilitator contracts. Adjustments to work package and facilitator contracts need to be considered in future.

- MPM: The OEE takes the internal and the external effectiveness into account and can be linked through the functional and hierarchical levels, connecting the top, middle and bottom level to one another. An MPM consists of a multi criteria framework and the temporal concept is taking the equipment related indicators into account, whilst the following criteria are missing:
    - Cost related indicators
    - Maintenance task related indicators
    - Learning and growth related indicators
    - Customer satisfaction related indicators
    - Health, safety and environment (HSE) related indicators
    - Employee satisfaction related indicators

In conclusion, the concept is considered as sufficient and target-oriented. However, it sets a baseline and can be improved upon in further steps. Especially by taking the possibilities from IoT and LSM into account.

6.3 Further Research Direction

Based on the results from the case study, the following next steps are planned:

1. Further application and additional research of the concept to other case studies and branches.
2. Applying state of the art data to the concept.
3. Long-term research. Investigate the benefits of the concept over long-term aspects.
4. Influences of latest maintenance strategies, like SM and LSM.

The developed concept has been applied to a SME in the waver industry. Further research in other branches is necessary to prove the concept.

Moreover, the data on which the calculations are based on, has been collected back in 2015. This data was sufficient for calculations, approximations and assumptions. However, further research is necessary to validate the concept with state of the art data.

Another aspect is the late impact of maintenance activities. A long-term case study helps to validate the influences of long-term actions of the maintenance concept and helps to validate the benefits. Especially, for the cost analysis this is fundamental.

Based on literature research, the OEM and customers, important parameters and success factors have been collected. Further, different outsourcing scenarios were taken into account. These parameters were analyzed and implemented into a service maintenance concept. As part of the developed concept, a service maintenance management system could be realized. On this system, latest maintenance concepts like LSM and SM could build up and make the system more effective and efficient.

6.4 Conclusion

To answer the research question - how can a service provided maintenance concept for Small and medium-sized enterprises (SMEs), based on total productive maintenance (TPM) and the corresponding key performance indicator (KPI) overall equipment effectiveness (OEE) look like, the thesis offers the following answer: the set up of a maintenance concept consists of seven steps. These steps help to set up a maintenance concept.

The total productive maintenance concept helped to answer the question, how the concept can be implemented and organised. Further its key performance indicator helps to track progress and measure the performance of the maintenance service provider and the developed maintenance concept.

In future, the increasing complexity of machines will result in the need for well planned maintenance activities. Latest studies show, that outsourcing the maintenance activities can offer a competitive advantage to SMEs. The developed model helps to tackle the challenges and supports the design of a service maintenance concept and its implementation in the SME.

7 Annex

7.1 Annex - Questionnaire

Questionaire Sheet

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Cycle Time ___________

Date ________________

Machine Name: __________ Machine Number: __________ Product: _________ Observer: _________

1.	Have you collected any data to the above mentioned machine?			Comment
	Yes ☐	No ☐		
2.	If no, what are the reasons for?			Comment
3.	If yes, which type of information did you collect and why?			Comment
4.	Did you measure the output and input of material the last year?			Comment
	Yes ☐	No ☐		
5.	If yes, how did you measure the input and the output?			
6.	Did you measure elements that influence the availability, like:			Comment
	1.	Breakdowns	Equipment Failure	
			Tooling Damage	
			Unplanned Maintenance	
	2.	Changeovers	Process Warm Up	
			Machine Changeovers	
			Material Shortage	
7.	Did you measure elements that influence the performance, like:			Comment
	1.	Idling / Stops	Product Misfeed	
			Component Jams	
			Product Flow Stoppage	
	2.	Reduced Speed	Level of machine operator time	
			Equipment age	
			Tooling Wear	
8.	Did you measure elements that influence the quality, like:			Comment
	1.	Start-Up losses	Tolerance Adjustment	
			Warm Up Process	
			Damage	
	2.	Yield / Rework / Scrap	Rejects	
			Rework	
			Cut offs	
9.	Did you collect data concerning maintenance?			Comment
	Yes ☐	No ☐		
10.	If yes, how did you collect it?			
11.	Would you share your information to enable Haas to improve with you the output of your production?			Comment
	Yes ☐	No ☐		

7.2 Annex – Date collection sheet for OEE

Data collection sheet for OEE

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Page ____ from ____
Cycle Time __________ Output per hour if machine is running the whole time__________
Date ______________
Machine Name: ____________ Machine Number: ____________ Product: __________ Observer: __________

Start	End	Supl. Nr.	Breakdown		Changeover	Idling / Stops	Speed loss	Start-Up losses	Scrap	Amount / Plates	Reason
			plann	unpl.							
07:10	07:20			x						20	Unplanned Maintenance, tool broke
08:15	08:20					x				10	No dough
09:30	09:45							x		14	Tolerance adjustment
10:40	10:52								x	15	Reused for creme

7.3 Annex – Measurement Plan

Measurement Plan

FRANZ HAAS • MEINCKE • MONDOMIX • STEINHOFF

Customer: ______________________________

Monteur: ______________ Date: ______________

Maschine type: ______________________________

Maschinen number: ______________ Format: ______________

Year of construction: ______________ Operating hours:

Performance (Wafersheet/min): ________

	Condition okay		Production possible
	yes	no	
Viscosity	☐	☐	Yes/No

1. Measurement with 100 ml flow cup - Time needed to see the whole again

a.)	1st measurument	Value is: ______ sec	e.)	6th measurument	Value is: ______ sec
b.)	2nd measurument	Value is: ______ sec	f.)	7th measurument	Value is: ______ sec
c.)	3rd measurument	Value is: ______ sec	g.)	8th measurument	Value is: ______ sec
d.)	4th measurument	Value is: ______ sec	h.)	9th measurument	Value is: ______ sec
e.)	5th measurument	Value is: ______ sec	i.)	10th measurument	Value is: ______ sec

k.) Average time Value is: ______ sec

l.) Controle dough

Comment: ______________________________

Moisture	☐	☐	Yes/No

1. Residual Moisture of the wavesheet with Halogen-moisture measurement (<2%)
   a.) Shredding the sheet
   b.) Drying until weight constant (3-5 mins) and document the weight loss in %

c.)	1st measurument	Value is: ______ %	h.)	6th measurument	Value is: ______ %
d.)	2nd measurument	Value is: ______ %	i.)	7th measurument	Value is: ______ %
e.)	3rd measurument	Value is: ______ %	j.)	8th measurument	Value is: ______ %
f.)	4th measurument	Value is: ______ %	k.)	9th measurument	Value is: ______ %
g.)	5th measurument	Value is: ______ %	l.)	10th measurument	Value is: ______ %

m.) Average % Value is: ______ %

d.) Controle dough

Comment: ______________________________

Measurement: State from 01.06.2017 Page 1 of 5 Pages

Measurement Plan

FRANZ HAAS • MEINCKE • MONDOMIX • STEINHOFF

	Condition okay yes	no	Production possible
Thickness of Wavershe et	☐	☐	Yes/No

1. Measure thickness via caliper in 3 positions (max deviation +/- 0,1 mm)

			Hunge side	Center	Lock Side	Average
1.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
2.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
3.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
4.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
5.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
6.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
7.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
8.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
9.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
10.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
11.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
12.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
13.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
14.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
15.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
16.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
17.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
18.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
19.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
20.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
21.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
22.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
23.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
24.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
25.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
26.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
27.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
28.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
29.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
30.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
31.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
32.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
33.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
34.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
35.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
36.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
37.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
38.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
39.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
40.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm

a.) Deviation

Comment: ____

____

____

____

Measurement: State from 01.06.2017

Measurement Plan

FRANZ HAAS • MEINCKE • MONDOMIX • STEINHOFF

	Condition okay		Production possible
	yes	no	
Thickness of Wavershet	☐	☐	Yes/No

1. Measure thickness via caliper in 3 positions (max deviation +/- 0,1 mm)

			Hunge side	Center	Lock Side	Average
41.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
42.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
43.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
44.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
45.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
46.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
47.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
48.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
49.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
50.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
51.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
52.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
53.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
54.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
55.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
56.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
57.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
58.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
59.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
60.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
61.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
62.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
63.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
64.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
65.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
66.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
67.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
68.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
69.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
70.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
71.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
72.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
73.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
74.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
75.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
76.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
77.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
78.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
79.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
80.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm

a.) Deviation

Comment: ____

____

____

Measurement: State from 01.08.2017

Page 3 of 5 Pages

Measurement Plan

FRANZ HAAS • MEINCKE • MONDOMIX • STEINHOFF

	Condition okay		Production possible
	yes	no	
Thickness of Waversheet	☐	☐	Yes/No

1. Measure thickness via caliper in 3 positions (max deviation +/- 0,1 mm)

			Hunge side	Center	Lock Side	Average
81.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
82.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
83.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
84.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
85.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
86.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
87.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
88.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
89.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
90.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
91.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
92.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
93.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
94.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
95.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
96.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
97.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
98.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
99.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
100.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
101.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
102.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
103.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
104.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
105.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
106.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
107.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
108.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
109.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
110.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
111.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
112.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
113.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
114.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
115.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
116.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
117.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
118.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
119.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm
120.	Plate	Value is:	____ mm	____ mm	____ mm	____ mm

a.) Deviation

Comment: ________________________________

____

____

Measurement: State from 01.08.2017 Page 4 of 5 Pages

Measurement Plan

FRANZ HAAS • MEINCKE • MONDOMIX • STEINHOFF

	Condition okay		Production possible
	yes	no	
Weight of Waversheet			Yes/No

1. Measure the weight of ten waversheets and take the average

1.	Weight of sheet	Value is: ______	mm	6.	Weight of sheet	Value is: ______	mm
2.	Weight of sheet	Value is: ______	mm	7.	Weight of sheet	Value is: ______	mm
3.	Weight of sheet	Value is: ______	mm	8.	Weight of sheet	Value is: ______	mm
4.	Weight of sheet	Value is: ______	mm	9.	Weight of sheet	Value is: ______	mm
5.	Weight of sheet	Value is: ______	mm	10.	Weight of sheet	Value is: ______	mm

k.) Average weight Value is: ______ mm

Comment: ______________________________

____

____

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12 List of Abbreviations

AM	Autonomous Maintenance
BCM	Business Centered maintenance
BSC	Balance Score Card
CATS	continuous improvement action teams
CATS	creative action teams
CIB	Centre for Industrial Management
CO	current output
COEE	current Overall Equipment Effectiveness
EM	Equipment Management
etc.	et cetera
FHW	Franz Haas Wafer
FMECA	failure modes effects and criticality analysis
HSE	Health, safety and environment
IoT	Internet of Things
JIPM	The Japanese Institute of Plant Maintenance
LCC	Lifecycle Cost
MPI	Maintenance Performance Indicators
MPM	Maintenance Performance Measurement
MSC	Maintenance Service Contract
NEE	Net Equipment Effectiveness
NEED	new equipment effectiveness determined
NMOD	new model of output that has to be determined
NOEE	new Overall Equipment Effectiveness
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
PIHDAS	Piepenbrock Instandhaltungs-Daten-Analyse-System
PM	Planned Maintenance
PNO	possible current output
RCM	Reliability centered maintenance
RFID	Radio Frequency Identification
ROA	Return on Assets
TEEP	Total Equipment Effective Equipment Productivity
TPEM	Total Productive Equipment Management
TPM	Total Productive Maintenance