Flexible TPM-organization in the automotive components production

Master Thesis
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In Cooperation with:

AUDI HUNGARIA MOTOR KFT.

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Kurzfassung

Die Automobilindustrie ist eine der größten und bedeutendsten wirtschaftlichen Branchen weltweit. Daher ist auch der Konkurrenzkampf innerhalb dieser Sparte sehr groß. Eine effiziente Produktion ist deshalb essenziel für wirtschaftlichen Erfolg. Die Produktion kann nur dann effizient sein wenn die Anlagenverfügbarkeit gegeben ist. Dies zu gewährleisten ist die Aufgabe der Instandhaltung. Wie gut und effizient die Instandhaltung ist hat daher auch direkten Einfluss auf die Leistung der Produktion.

Diese Arbeit zielt darauf ab, die Instandhaltung effizienter, flexibler und letzten Endes auch kostengünstiger zu gestalten. Diese Arbeit wurde speziell für die Anforderungen der AUDI HUNGARIA MOTOR Kft. In Györ verfasst. Das Motorenwerk in Györ produziert an circa 40 Produktionslinien Hauptbestandteile des Motors wie Motorblock, Zylinderkopf aber auch Nockenwellen, Kurbelwellen und Pleuel. Des Weiteren gibt es auch noch einige Montagelinien an denen die Teile aus eigener Produktion und von Zulieferern zu einem fertigen Motor zusammengefügt werden. Neben einer Literaturrecherche zum Thema Instandhaltung war die Aufnahme der Ist Situation der Instandhaltungsorganisation und deren Prozesse eine Hauptaufgabe dieser Arbeit. Die aktuell umgesetzte „Total Productive Maintenance“ Strategie (TPM) wurde untersucht um Stärken und Schwächen der aktuellen Organisation zu eruieren. Basierend auf diesen Ergebnissen wurden Anforderungen für die Zukunft definiert, die in weiterer Folge in das neu erstellte Konzept eingeflossen sind. Im Konzept wurden die Instandhaltungsorganisation und die Instandhaltungsstrategie überarbeitet, sowie auch die Prozesse weiterentwickelt.

Die Ergebnisse der Arbeit wurden in erste Linie an der Verbessureng der „Overall Equipment Effectiveness“ (OEE) als auch an der Flexibilität der Organisation sowie an den Gesamtkosten der Instandhaltung gemessen. Zuletzt wurden noch Vorschläge zu weiteren Untersuchungen gemacht die in diese Arbeit nicht behandelt wurden, da sie den Rahmen der selbigen sprengen würden.

Abstract

As one of the biggest and most important economical branches, the automotive industry is a very competitive business. To stay competitive, an efficient production is essential. Production can only be efficient if the availability of the production equipment is sufficiently high. To guarantee a high production equipment availability is the response of maintenance. The performance of maintenance directly influences the performance of the entire production.
The target of the thesis is to improve maintenance as to efficiency, flexibility and even costs. This thesis was exclusively done for AUDI HUNGARIA MOTOR Kft.in Györ. On roughly 40 production lines the plant in Györ produces main parts for a car engine such as the motor block, the cylinder-head but also the cam-shaft the crank-shaft and the con-rod. In addition to these lines there are also several assembly lines where their own produced parts and the parts delivered by suppliers are merged together. Beside a literature research concerning maintenance in general, analyzing the current maintenance organization, the related processes and the general performance where the main tasks of investigation. Analyzing the currently carried out “Total Productive Maintenance” (TPM) strategy to show weaknesses and potentials was the next step. Requirements for further improvements, based on the findings were defined. These findings were integrated in the new concept. Within the concept suggestions for improvement of the TPM strategy in general as well as the structural and the process organization were presented.
For measuring the results the “Overall Equipment Effectiveness” (OEE), the flexibility but even the overall maintenance costs were taken into account. Some points for further investigation were given at the end of the thesis. However, these investigations are beyond the scope of this thesis.

Foreword

This diploma thesis was written on the institute of Mechanical Engineering and Business Informatics under the lead of Univ.-Prof. Dipl.-Ing. Dr.techn. Siegfried Vössner in cooperation with the AUDI HUNGARIA MOTOR Kft (AHM). in Györ from July 2015 until January 2015. The purpose of this thesis was the development of a concept for a flexible TPM-Organization in the automotive car engine production.

My special thanks to my supervisor at AHM Albert Fazekas. Further I want to thank my supervisors from the university Ass.Prof. Dipl.-Ing. Dr.techn Gerald Christian Lichtenegger and Dipl.-Ing. Christoph Wolfsgruber for their fantastic support.
Further I want to thank my parents my grandfather and my girlfriend for their great support during the entire study.

Content

1 Introduction

The automotive industry, with big players distributed over the whole world, is a very important economical branch. With an annual turnover of approximately 367.9 Billion € (2014)[1] just for the German automotive industry, the dimension is obvious. The competition to stay competitive is a continuous big challenge. The most important objective is, that the product has to meet customer requirements in terms of design, quality and also in the final selling price. For the last two terms, quality and price, the production process plays an important role. An efficient production of the car and its parts has a main influence on the quality of the product.
For efficient production, various items are important and linked together, some important terms will be explained:

People
It is essential to have the right people in the right positions. They need to have all skills to fulfill the required tasks and to ensure continuous improvement. For ensuring effective production, a lot of people are involved in the process: blue collar workers, technical staff, people with no technical background and managers. All the people of these different groups have to cooperate for a good economical result. (Gutenberg, 1966)

Equipment and Technology
To have the required working equipment as well as to be aware of new technologies (technological S-curve[2]) entering the market, is essential. Equipment and technologies, especially in the manufacturing industry are changing very fast. To find the right mix of “traditional” and “innovative” production equipment for a powerful production setup is a challenge. When decisions for new equipment are made, all aspects with regards to people (is the required know-how for the new technology available?) and maintenance (is the maintenance prepared for the new technology?) have to be considered as well. (Ramsauer & Pointner, 2013)

Maintenance
Often seen as just a cost factor, maintenance is a demanding part of production. For staying competitive and to ensure an efficient and robust production, maintenance is an unavoidable part in the entire business process. To find the right strategy and organization which support an efficient production now and in the future is a big challenge and a key success factor.
As mentioned above, maintenance is, together with other sub- or supporting business processes, one vital process alongside production, which is regarded as the main process. All these supporting processes have the goal to establish an efficient production process. (Weißenbach, 2012)
In this thesis the focus will be on maintenance and the overall organization of maintenance. (Weißenbach, 2012) Some supporting processes, such as maintenance, to the main process the production are shown in figure 1.

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[1] Quelle: VDA (Verband der Automobilindustrie), https://www.vda.de/de/services/zahlen-und-daten/zahlen-und-daten-uebersicht.html
[2] Christensen C.: Exploring the Limits of the Technology S-Curve. Part 1: Component Technologies, Production and Operations Management 1 (1992)4, p. 340 in Christensen C.: The Innovator´s Dilemma – When New Technologies Cause Great Firms to Fail. Boston 1997

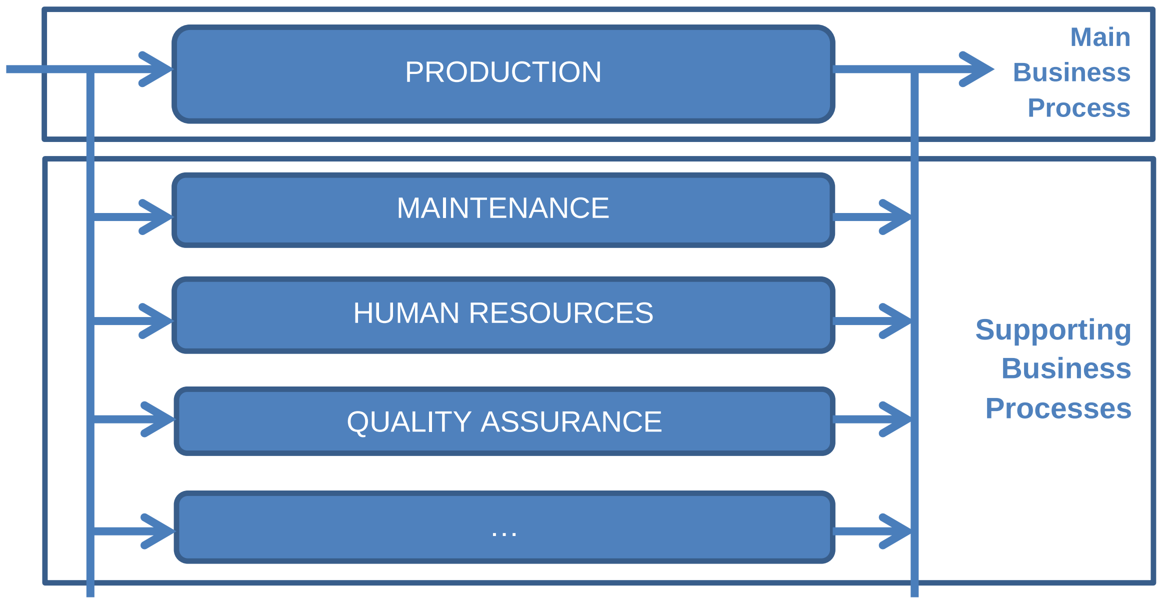

Figure 1: Main and supporting business processes; modified from Weißenbach (2012)

Over the last few decades, maintenance and maintenance strategies have changed considerably. Unplanned maintenance was practiced for a long time after the first industrial revolution. (Moubray, 2000) Unplanned or reactive maintenance means, that repair is done only after a machine has already broken down.
Planned maintenance was the next practiced maintenance strategy which is used until now. Planned maintenance consists of predefined inspections and repair done after specified intervals or production hours. The "up to date" maintenance strategy at the moment is condition based maintenance. The target of this strategy is to predict potential machine break-downs based on machine conditions. That strategy brings a lot of advantage for a fast and proper solution of the problem. What will come next? The challenge is to reduce unplanned maintenance and to perform maintenance tasks just when they are necessary (condition monitoring). (Moubray, 2000)
The optimum maintenance can be summarized as "as little as possible and as often as necessary to prevent production from breakdown".

Moubray (2000) presents an evolution in maintenance in three phases:

- The first generation, includes corrective maintenance.
- The second generation, basically works with preventive maintenance.
- The third generation, contains Total Productive Maintenance (TPM), reliability-centered maintenance and predictive maintenance.

How the strategies have changed according to Moubray (2000) over the time can be seen infigure 2 below.

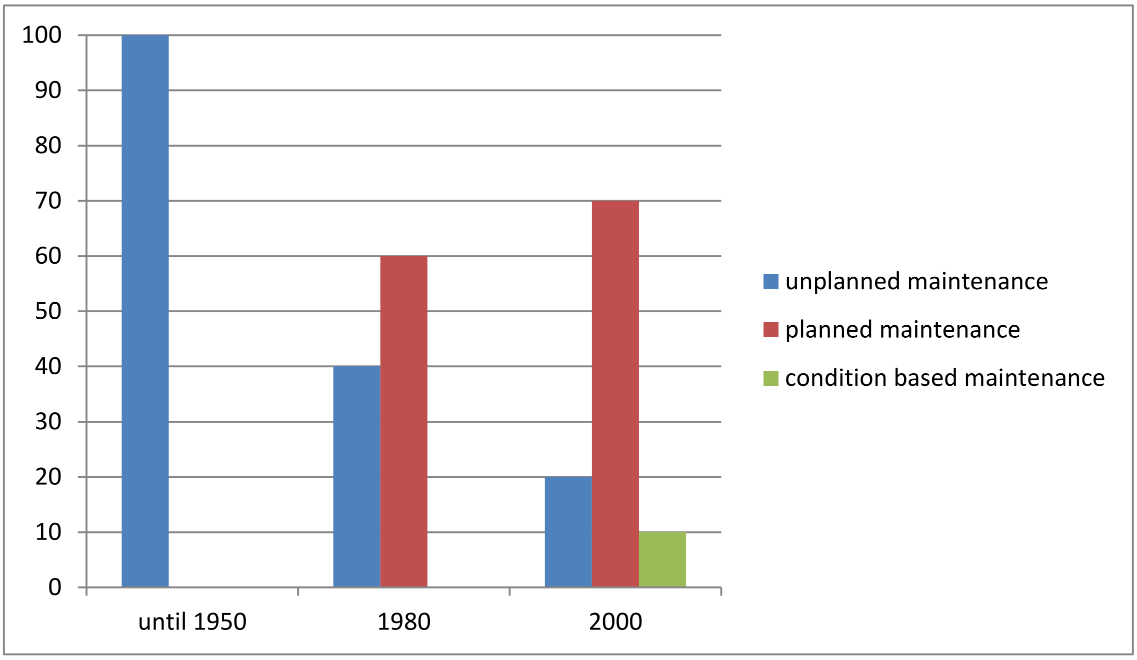

Figure 2: Change of maintenance strategies over the last decades; modified from Moubray (2000)

1.1 Goals of the Thesis

The goal of this thesis is the development of a concept for a flexible TPM-Organization for the AUDI HUNGARIA car engine production. The production and the production maintenance are undergoing radical changes. *Industry 4.0*[3], *Smart Factory*[4] (Smart production and Smart Maintenance) and *Big Data*[5] are terms which go along with the computerization and the connection of the production equipment. Gigabytes of equipment data are collected each day. How to use new technologies and data for an efficient production is a challenge. The other point is, what the maintenance organization in terms of the structural and process organization should look like in order to be efficient, to be prepared for the future challenges and to stay competitive.

1.2 Field of Research

AUDI HUNGARIA MOTOR KFT.[6] (AHM) in Györ is the largest car engine production unit in the world. It is obvious that a huge amount of production equipment is necessary for a production volume of approximately two million engines per year.
The maintenance of the existing assets is a critical task. On the one hand the costs for maintenance in general are enormously high. On the other hand an interrupted production

[3] Kagermann H., Lukas W. D., Wahlster W., Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. Industriellen Revolution, VDI Nachrichten, April 2011
[4] Bundesministerium für Bildung und Forschung, Zukunftsprojekt Industrie 4.0, 2011
[5] Leskovec J., Rajaraman A., Ulman J. D., Mining of Massive Datasets,2. Auflage, Cambridge University Press, Cambridge
[6] Founded 1993, Production volume ~2million car engines (2014), 5947 employees (2015)

process caused by an engine breakdown is the worst case and causes costs too. Under investigation is the entire car engine component production with all needed production lines

1.3 Approach

Divided in four main phases a new concept for the organization of maintenance will be developed.

Phase 1) Definition of the term maintenance and a comparison to the German term “Instandhaltung”. List and explanation of important terms in connection with maintenance and TPM. Determination of key performance indicators for maintenance.

Phase 2) Determination of the as-is state at AUDI HUNGARIA MOTOR KFT. (AHM), under particular consideration of the TPM organization and processes. At first, an overview of the company and the entire production will be given. Next, the organization and the processes for TPM will be explained in detail. In the summary and conclusion weaknesses of the current organization will be listed.

Phase 3) Based on the results and findings from Phase 2 in this part of the thesis requirements for a new organization will be listed: in general requirements for an efficient maintenance as well as specific requirements specially for the demands of AHM.

Phase 4) A description of a target state for a TPM organization will be provided, especially focusing on structure an process organization as well as on an appropriate strategy.

2 Maintenance

Fast changing technologies and high costs for new production equipment, are reasons why maintenance of industrial equipment has become a growing topic of discussion. Equipment care has become increasingly important. Generally speaking, maintenance simply consists of keeping equipment in working condition. (Bartz, et al., 2014)
Maintenance also is fundamental for equipment availability. Today, faced with the phenomenon of globalization, maintenance has moved into the focus of quality and productivity management. For a functioning industry, maintenance plays a vital role. It is worthless for a production manager to seek an increase in productivity if the equipment does not receive proper maintenance. (Bartz, et al., 2014)

Generally, maintenance of production equipment has five main functions which have to be fulfilled[7]:

I. Conservation of the target state
II. Reconstruction of the target state
III. Reduce breakdowns
IV. Increase reliability
V. Determination of as-is state over the entire lifecycle of an asset

Maintenance should ensure availability and an appropriate performance of the technical equipment under economically acceptable costs.

2.1 Definitions

At first the differences between the German word "Instandhaltung" and the English term "*Maintenance*" will be shown. AUDI is a German company and therefore the term "Instandhaltung" is used also within this thesis. The differences in definition of the terms will be explained.

According to DIN 31051[8] "Instandhaltung" consists of the four items described below. The English term *"Maintenance"* consist of *"Inspection"* and *"Service"*. *"Overhaul"* can be divided in *"Repair"* and *"Improvement"* (see Figure 3):

[7] Information are from AUDI internal documents
[8] DIN31051,2003, p3-5 (Grundlagen der Instandhaltung)

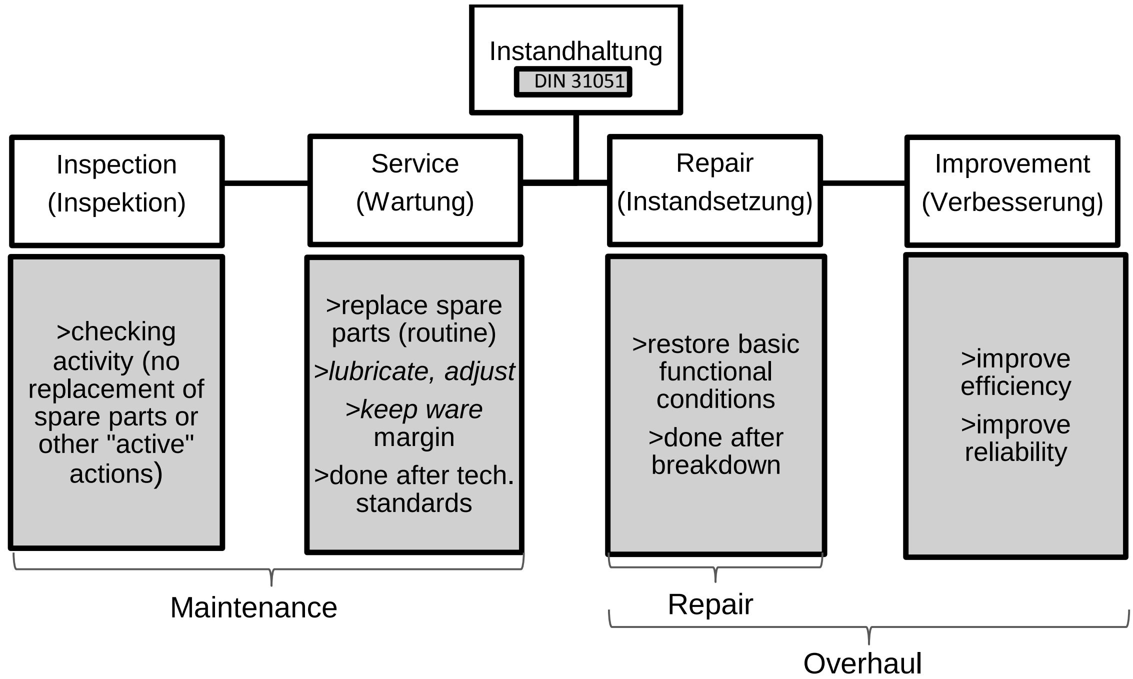

Figure 3: “Instandhaltung” and terms according to DIN 31051

2.1.1 Inspection (Inspektion)

All actions for defining and assessing of the as-is state of a specific equipment including the identification of the reasons for the wear and the deviation of necessary actions for the further use. (DIN 31051)

2.1.2 Service (Wartung)

Service contains actions for delaying the wear margin and is done during the use of the equipment. Service is done after technical standards (mileage, period) or equipment manufacturer provisions. Most of the time Service is done in predefined periods by professional staff. To decrease the wear and increase the lifetime is the objective. Often Service is a precondition for guarantee. (DIN 31051)

2.1.3 Repair (Instandsetzung)

The action of bringing back a defective object into the original functional condition except improvements is termed Repair. (DIN 31051)

2.1.4 Improvement (Verbesserung)

A combination of technical and administrative actions as well as management actions for improving the functional reliability of a specific equipment without changing the required functions is called Improvement. (DIN 31051)

In the English language the term “Instandhaltung” contains the terms maintenance, repair, and overhaul which will be explained:

Maintenance
Compared to the German term the English term maintenance includes inspection as well as services. The periodical inspections or inspections after a certain period of operation and also the standard predefined services are included in maintenance activities.

Repair
Repair is similar to the German term “Instandsetzung”. It is needed after a breakdown of a machine to bring the equipment back to the original and functional condition.

Overhaul
Overhaul includes Repair which is similar to “Instandsetzung” and improvement or “Verbesserungen”. Both terms are included in overhaul.

In the thesis terms such as “autonomous maintenance”, “planned maintenance” and “unplanned maintenance” are a central issue of this thesis and will be occur frequently within the thesis. At AUDI the definitions of these terms are not concurrent with the definitions according to DIN 31051. What the differences are will be described hereunder.

- Autonomous maintenance:
  Includes just inspection and service activities (similar to the definition of maintenance according to DIN 31051).

- Planned maintenance:
  Beside service activities mainly repairs are done. Beside these repair activities improvements to increase reliability are done as well.

- Unplanned maintenance:
  Unplanned maintenance are troubleshooting activities which are carried out after a machine has broken down already. All unplanned activities, are repair activities.

2.2 Related Terms and Parameters

In connection with maintenance there are a lot of terms which occur very often, and which are very important to understand. For the purpose of comprehension of this thesis, definitions of the most important terms are given. Beside these terms there are so called Key Performance Indicators (KPIs) for the need of maintenance, which defines the actions which have to be set and the performance of the maintenance activities.

2.2.1 Effectiveness

Clements (1991) describes effectiveness as "*how well the product/process satisfies end user or customer demands*". Effectiveness varies from zero to one and includes all value elements. One form of how effectiveness can be described is given by Berger (1993):

$$Effectiveness = Availability * Reliability * Maintainability * Capability$$

2.2.2 Mean Downtime

"In organizational management, mean down time (MDT) is the average time that a system is non-operational. This includes all downtime associated with repair, corrective and preventive maintenance, self-imposed downtime, and any logistics or administrative delays. The inclusion of delay times distinguishes mean down time from mean time to repair (MTTR), which includes only downtime specifically attributable to repairs." (Smith, 2011)

$$MDT = \frac{Total\ downtime}{Number\ of\ downtimes}$$

2.2.3 Mean Time to Repair

Mean time to repair (MTTR) is the average time required to troubleshoot and repair failed equipment and return it to normal operating conditions. It is a basic technical measure of the maintainability of equipment and repairable parts. Maintenance time is defined as the time between the start of the incident and the moment the system is returned to production. Generally speaking it means how long the equipment is out of production. This includes notification time, diagnostic time, fixing time, waiting time, reassembly, alignment, calibration, testing time, back to production etc. It generally does not take into account lead-time for parts. MTTR reflects how well an organization can respond to a problem and repair it. (Anon., 2015)

$$MTTR = \frac{Total\ maintenance\ time}{Number\ of\ maintenance\ actions}$$

2.2.4 Mean Time between Failures

Mean time between failures (MTBF) is the duration between failures of a system during operation. (Jones, 2006)
The definition of MTBF depends on the definition of what is considered a system failure. *"For complex, repairable systems, failures are considered to be those out of design conditions which place the system out of service and into a state of required repair. Failures which occur that can be left or maintained in an unrepaired condition, and do not place the system out of service, are not considered failures under this definition."* (Colombo & Sáiz de Bustamante, 1988) In figure 5 the timeline of the production states can be seen.

$$\mathrm{MTBF} = \frac{Planned\ production\ time - Downtime}{Number\ of\ failures\ during\ planned\ production\ time}$$

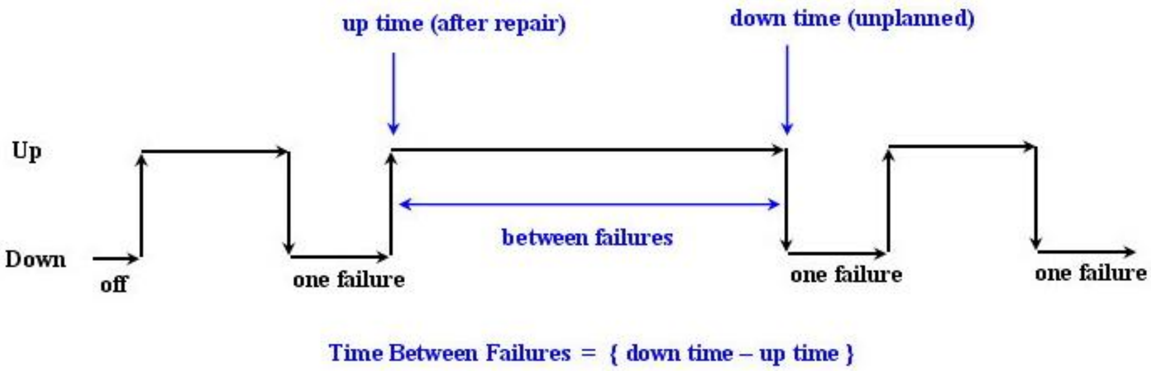

Figure 4: Up- and down- times of production equipment; Anon (2015)

2.2.5 Availability

Availability deals with the durability of up-time for operations and is a measure of how long the system is up and working well. Availability can be expressed in many different variants, often availability is expressed as (up-time)/ (up-time + downtime). Up-time and downtime refer to binary conditions, either the system is working or not. Up-time refers to a capability to perform the task and downtime refers to not being able to perform the task, i.e., uptime==not downtime (Barringer, 1997).

According to Ireson (1996) frequently used availability terms are explained below.

Inherent availability[9], as seen by maintenance personnel, (excludes preventive maintenance outages, supply delays, and administrative delays) is defined as:

$$A_i = \frac{MTBF}{(MTBF + MTTR)}$$

Achieved availability[10], as seen by the maintenance department, (includes both corrective and preventive maintenance but does not include supply delays and administrative delays) is defined as:

$$A_a = \frac{MTBF}{(MTBM + MAMT)}$$

Operational availability[11], as seen by the user, is defined as:

$$A_o = \frac{MTBM}{(MTBM + MDT)}$$

Availability can also be differentiated in absolute availability, measured over the entire calendar year, and relative availability, measured over the planned production time. (Katila, 2000)

[9] MTBF Meantime between failure; MTTR Meantime to repair
[10] MTBM Meantime between maintenance; MAMT Mean active maintenance time
[11] MDT Mean downtime

$$A_{abs} = \frac{Calendar\ time\ - Downtime}{Calendar\ time} * 100\%$$

$$A_{rel} = \frac{Planned\ productio\ time - Downtime}{Planned\ production\ time} * 100\%$$

2.2.6 Reliability

One definition of reliability and how this term is understood in production is given by Barringer (1997).
"Reliability deals with reducing the frequency of failures over a certain time interval and is a measure of the probability for failure-free operation during a given interval, i.e., it is a measure of success for a failure free operation." (Barringer, 1997)
"For the user of a product, reliability is measured by a long, failure free, operation. Long periods of failure free interruptions result in increased productive capability while requiring fewer spare parts and less manpower for maintenance activities which again results in lower costs. For the supplier of a product, reliability is measured by completing a failure free warranty period under specified operating conditions with few failures during the designated life span of the product." (Barringer, 1997)

2.2.7 Maintainability

"Maintainability deals with duration of maintenance outages or how long it takes to achieve the maintenance. Maintenance (all actions necessary for retaining an item in, or restoring an item to, a specified, good condition) is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance. Maintainability characteristics are usually determined by equipment design which set maintenance procedures and determine the length of repair times." (Barringer, 1997)
"The key figure of merit for maintainability is often the mean time to repair (MTTR) and a limit for the maximum repair time. Qualitatively it refers to how easy/ difficult hardware or software is restored to a functioning state. Quantitatively it has probabilities and is measured based on the total down time for maintenance including all time for: diagnosis, trouble shooting, tear-down, removal/replacement, active repair time, verification testing that the repair is adequate, delays for logistic movements, and administrative maintenance delays."
(Barringer, 1997)

2.2.8 Capability/ Productivity

"Capability deals with productive output compared to inherent productive output which is a measure of how well the production activity is performed. This index measures the systems capability to perform the intended function on a system basis. Often the term is synonymous with productivity which is the product of efficiency multiplied by utilization. Efficiency measures the productive work output versus the work input. Utilization is the ratio of time spent on productive efforts to the total time consumed." (Barringer, 1997)

2.2.9 **Overall Equipment Effectiveness**

Overall equipment effectiveness (OEE) measure was proposed by Nakajima (1988) as an approach to evaluate the progress achieved through the improvement initiatives carried out as part of his proposed total productive maintenance (TPM) philosophy. Nakajima (1988) defines OEE as "*a metric or measure for the evaluation of equipment effectiveness*". Accordingly, OEE attempts to identify production losses and other indirect and "hidden" costs, which according to Ericsson (1997) are those that contribute to a large proportion of the total cost of production. These losses are defined as a function of a number of mutually exclusive components (Huang, et al., 2003) which are: availability (A), performance (P) and quality (Q). The OEE is the result achieved by multiplying these three factors together as shown by the following equation:

$$OEE = A * P * Q$$

OEE Factors:
The **availability** factor measures the total time that the system is not operating because of breakdowns, set-up, adjustment, and other stoppages (Jonsson, 1999) It is traditionally calculated using the Nakajima's (1988) formula presented below. In this formula, loading time refers to the length of operation of any equipment after excluding any planned activities that may have interrupted the production, for example: schedule and planned maintenance, official production breaks, process improvement initiatives or equipment tests, maintenance performed by the machine operator (e.g. equipment cleaning), operator training, etc. (Garza-Reyes, et al., 2014):

$$A = \frac{Loading\ time - Downtime}{Loading\ time}$$

The second OEE element, **performance rate**, measures the ratio of the actual operating speed of the equipment (e.g. the ideal speed minus speed losses, minor stoppages and idling) to its ideal speed (Jonsson, 1999). For calculating the performance rate several formulas are existent. However, Nakajima (1988) measures a fixed amount of output, and in his definition of "performance", it indicates the actual deviation in production in time from ideal cycle time. Performance (P) is calculated using the following Nakajima's (1988) equation (Garza-Reyes, et al., 2010):

$$P = \frac{Ideal\ cycle\ time * Output}{Operating\ time}$$

The third element of OEE is **quality** (Q). It indicates the proportion of defective production to the total production volume. An important characteristic that should be noted is that the quality concept, as defined by Nakajima (1988) only involves defects that occur in that designated stage of production, usually on a specific machine or production line and not elsewhere. Quality (Q) is calculated using the Nakajima's (1988) equation presented below (Garza-Reyes, et al., 2010):

$$Q = \frac{Input - Volume\ of\ quality\ defects}{Input}$$

Six Big Losses:

Nakajima´s description of the OEE including availability, performance and quality is already known. For calculating the OEE value, these terms have to be divided into specific events. Availability for example contains “breakdowns” and “setup and adjustment” what that can also be summarized as downtime. Similar to availability, performance and quality can also be split up. These events are known as the six big losses. To increase the OEE these six big losses have to be minimized. (Nakajima, 1988)

The six big losses and the influence on availability, performance and quality defined by Nakajima (1988) can be seen in figure 4 below. To reduce this six big losses is a main goal of TPM.

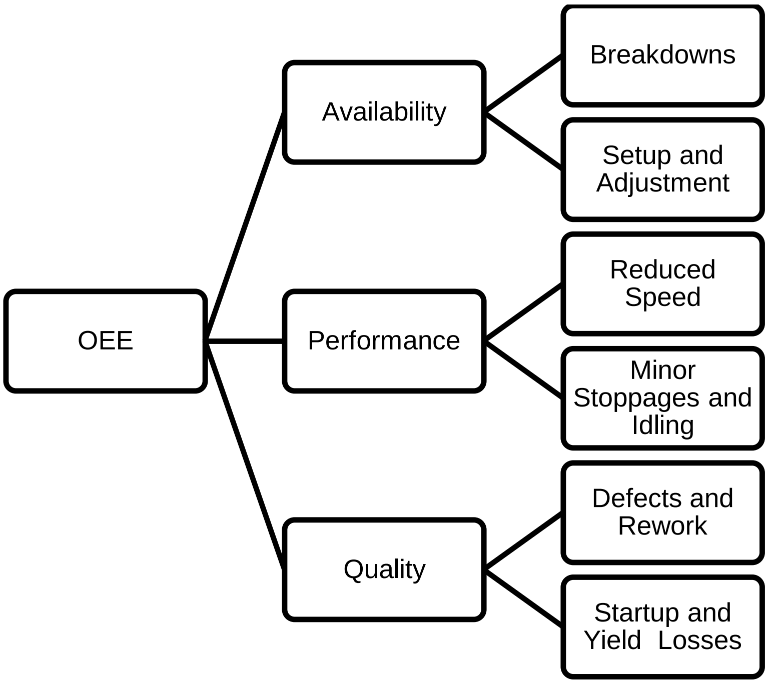

Figure 5: Overview over the six big equipment losses; adapted from Nakajima (1988)

Breakdown:

“Sporadic and chronic equipment failure/ breakdowns sudden and sporadic breakdowns are infrequent and result from the deterioration of the mechanical and electrical operating components.” (Katila, 2000) Most of the times breakdowns disturb or interrupt the production and therefore have to be avoided.

Setup and Adjustment:

“Setup and adjustment or make-ready and equipment adjustment. With shorter run lengths, smaller batches and more make-readies, reduction in make-ready time and new job adjustments is important to increase the efficiency.” (Katila, 2000)

Reduced Speed:

Production is running slower than rated speed due to several reasons. (Katila, 2000)

Minor Stops and Idling:
"Minor stops and idling or material abnormalities and slight machine malfunctions that can requre replacing materials or resetting press components". (Katila, 2000) Reasons can be that the, material (raw material from suppliers) has not the requred qualiy or the automated tool change is not workin correctly. (Katila, 2000)

Defects and Rework:
"Defective end products, for whatever reason, must be treated as a loss and therefore eliminated." (Katila, 2000)

Startup and Yield Losses:
"Startup loss is lost time after the make-ready is complete and production sheets/ signatures are counted, at reduced speed." (Katila, 2000)

2.3 Maintenance Management

Managing the maintenance activities is a very complex task and requires a holistic view on all business processes. How production and maintenance can be combined in the most efficient way and which conflict potential exists in this relationship is an issue the maintenance management has to know. The maintenance management also has to be aware of how a decision for a new production equipment can affect or influence the maintenance activities in the future. There are variety of further skills and influencing factors for the maintenance management activities themselves to be considered.
Strategic planning and the continuous improvement of the applied strategy are the main tasks. The maintenance management also has to deal with the supervision of the current maintenance activities, what the actual performance is like and where improvements have to be made to achieve top maintenance performance. Thus the work of the maintenance management consists of short term actions, supervision and the reporting, mid-term actions like the suggestion and implementation of improvements and finally long term planning which includes mainly strategic planning. (Strunz, 2012)

2.3.1 Targets of Maintenance

The overall target of maintenance is to keep the production equipment running, and to guarantee ready-to-use production equipment. Zero breakdowns is the target each person involved in maintenance aims for.
Strunz (2012) divided the working targets of maintenance in three groups: cost targets, safety targets and production targets (Table 1).

Working Targets of Maintenance		
Cost Targets	**Safety Targets**	**Production Targets**
Reduce maintenance expenses	Eliminate health hazards	Ensure asset availability
Reduce downtime costs, Reduce production losses	Ensure work safety	Autonomy by finding the optimum maintenance mix

Table 1: Targets of maintenance; modified from Strunz (2012)

2.3.2 Maintenance Strategies

Over the last decades, various maintenance strategies have been developed. Each strategy is applied to a specific use and has a justified existence. (Moubray, 1990) The big challenge is to find the right strategy or the right strategy mix for the situation. Which strategy in each particular case will lead to success depends on various influencing factors. In the following chapter some common strategies will be explained. In figure 6 strategies in accordance to DIN 13306 are shown.

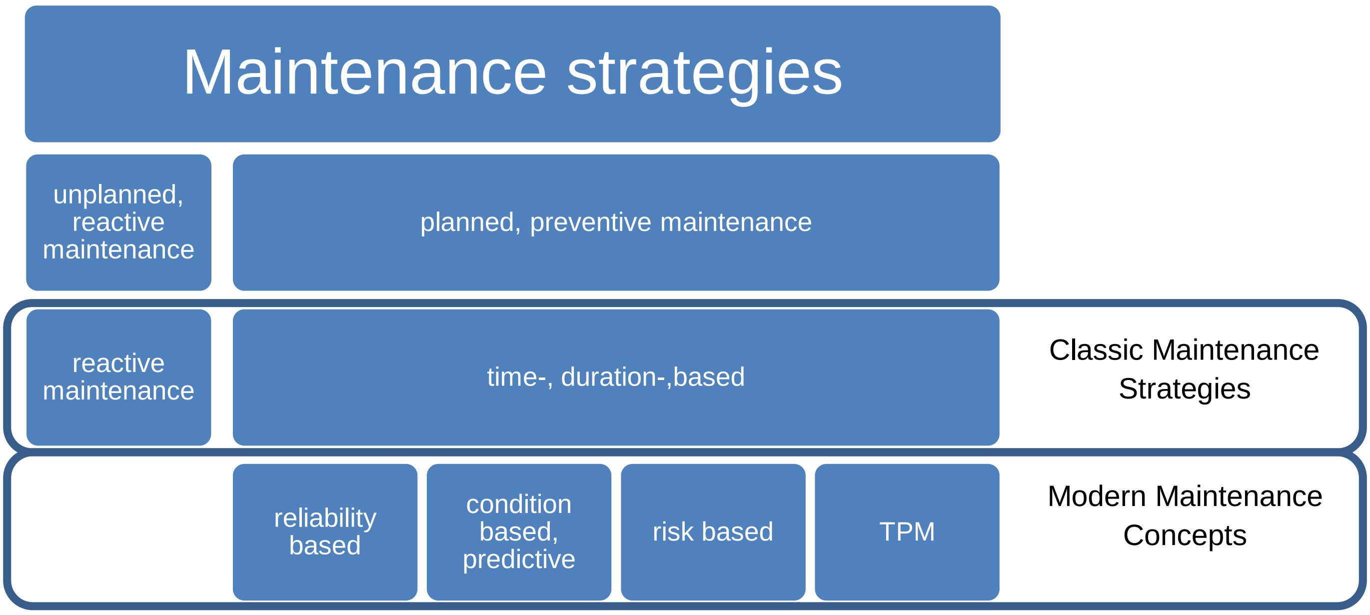

Figure 6: Overview of maintenance strategies; modified from (DIN EN 13306, 2001)

2.3.2.1 Reactive Maintenance/ Crash strategy:

Reactive maintenance (also known as "breakdown maintenance") is based on repairs that are done when equipment has already failed. Reactive maintenance focuses on restoring the equipment to its normal operating condition. The broken-down equipment is returned to a working state within service specifications by replacing or repairing faulty parts and components. (Rötzel, 2005)
Reactive maintenance can also be the right strategy, if the production equipment is required to be available all the time (Schimmelpfeng & Steffen, 2000) Furthermore, this applies if

redundant equipment is existent and the required availability is given even if one machine brakes down (Rötzel, 2005).

Ad-hoc repairs cost more than planned repairs. Thus the maintenance action itself is very expensive compared to planned maintenance. An interrupted production caused by an equipment breakdown can cause severe costs. Advantages and disadvantages of this strategy are listed below (Stoneham, 1998), (Benz & Scheiffele, 2001):

Advantages:

- Efficient if the strategy is used for specific, non-critical or safety relevant assets
- The ware margin of the part is totally used
- No maintenance costs until emergency repair occur
- Little information required

Disadvantages:

- Activities cannot be planned (no information about when and which part will breakdown)
- Required reliability cannot be guaranteed
- Risk of long downtimes
- High costs for repair

2.3.2.2 Planned or Preventive Maintenance:

Contrary to breakdown maintenance, the aim of planned maintenance is to prevent equipment from breakdown. The maintenance tasks are predefined and scheduled for each production unit. (Schimmelpfeng & Steffen, 2000)
Planned maintenance is done if independent from the condition of the asset, preventive maintenance actions are performed in cyclical intervals. (Schimmelpfeng & Steffen, 2000) (Nebl & Prüss, 2006)
In figure 7 the ware margin over time and the planned time of replacement can be seen.

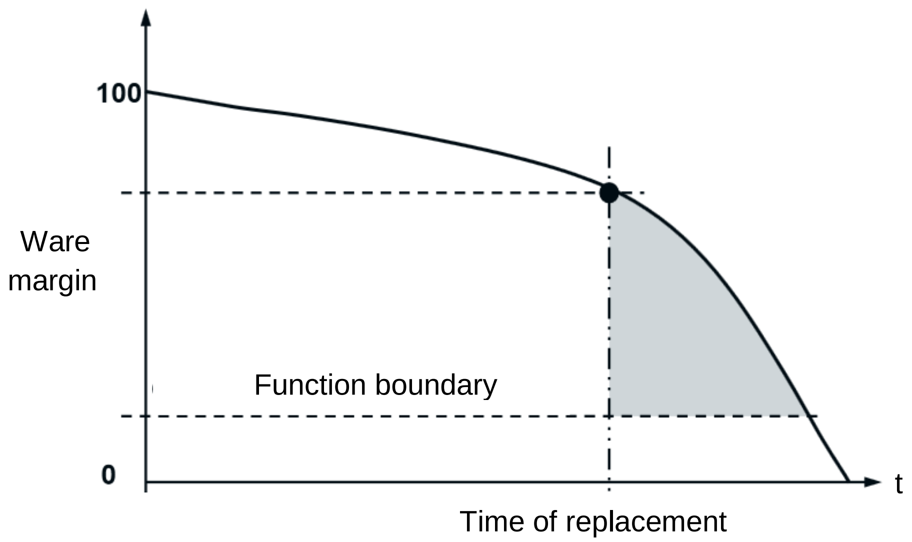

Figure 7: Preventive maintenance; modified from Ryll & Freund (2009)

The advantages and disadvantages of this strategy are listed below (Benz & Scheiffele, 2001):

Advantages:

- High reliability and availability
- The duration of the maintenance activities can be planned
- Spare parts can be prepared
- Time of implementation can be planned
- The staffing can be done in advance
- Cost reduction (no additional unexpected repair activities)

Disadvantages:

- High effort for planning and data acquisition necessary
- Ware margin of the spare parts are not totally used
- Running maintenance costs are comparably high

2.3.2.3 Reliability-centered Maintenance (RCM)

“Reliability-centered maintenance (RCM) is a structured methodology for determining the maintenance requirement of any physical asset in its operating context” (Moubray, 1990). The primary objective of RCM is to preserve system function (Smith, 1993). As such, the indiscriminate maintenance tasks which are not cost-effective in preserving system function should be eliminated (Anderson & Neri, 1990). The US Department of Defense (DOD),in 1975 directed that the maintenance concept be named “reliability-centered maintenance”.

2.3.2.4 Condition based Maintenance (CBM), Predictive Maintenance (PM)

CBM is a maintenance program that recommends maintenance actions based on the information collected through condition monitoring. CBM attempts to avoid unnecessary maintenance tasks by taking maintenance actions only when there is evidence of abnormal behaviors of a physical asset. A CBM program, if properly established and effectively implemented, can significantly reduce maintenance cost by reducing the number of unnecessary scheduled preventive maintenance operations (Jardine, et al., 2006).
The ware margin over time and the time of replacement can be seen in figure 8.

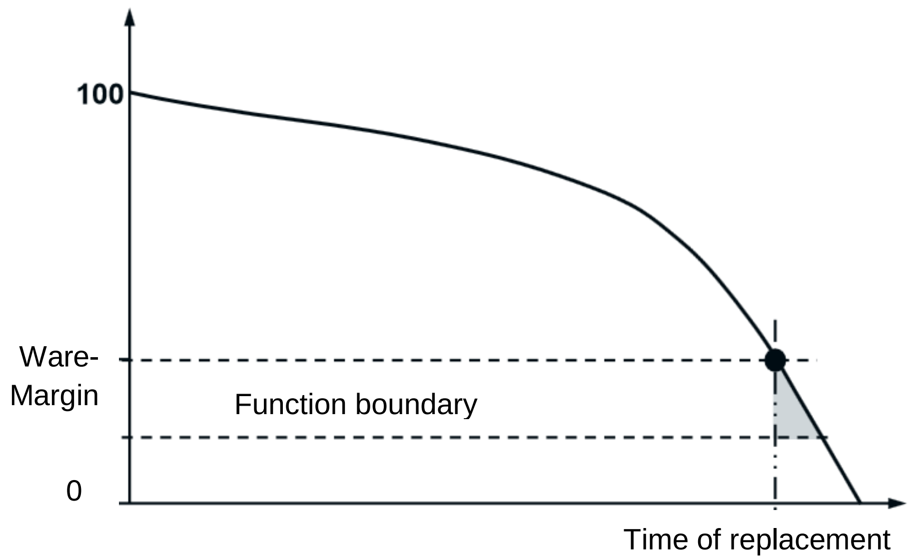

Figure 8: Predictive maintenance, modified from Ryll & Freund (2009)

Advantages and disadvantages are listed below (Stoneham, 1998), (Benz & Scheiffele, 2001):

Advantages:

- High reliability and availability of the assets
- Nearly total use of the ware margin of the asset
- Easy to plan, because asset conditions are known
- High work safety
- Reduces the need of control activities

Disadvantages:

- More complex inspections are necessary
- Specific know how for analyzing data required
- Additional cost for condition monitoring equipment

A CBM program consists of three key steps (Jardine, et al., 2006):

- Data acquisition step (information collection), to obtain data relevant to system health.
- Data processing step (information handling), to handle and analyze the data or signals collected in step 1 for better understanding and interpretation of the data.
- Maintenance decision-making step (decision-making), to recommend efficient maintenance policies.

Condition-monitoring techniques can be classified according to the type of symptoms they are designed to detect. The classifications are as follows (Moubray, 1990):

- Dynamic effects, such as vibration and noise levels;
- Particles released into the environment;
- Chemicals released into the environment;
- Physical effects, such as cracks, fractures, wear and deformation;
- Temperature rise in the equipment;
- Electric effects, such as resistance, conductivity, dielectric strength, etc.

2.3.2.5 Risk based Maintenance

Risk-based maintenance framework consists of two main phases (Arunraj, 2007):

1. Risk assessment.
2. Maintenance planning based on risk.

The main aim of this methodology is to reduce the overall risk that may result as the consequence of unexpected failures of operating facilities (Khan & Haddara, 2004). The inspection and maintenance activities are prioritized on the basis of quantified risk caused due to failure of the components, so that the total risk can be minimized using risk-based maintenance. The high-risk components are inspected and maintained usually with greater frequency and thoroughness and are maintained in a greater manner, to achieve tolerable risk criteria (Brown & May, 2003).

Planned Maintenance vs. Condition based Maintenance

The following two diagrams visualize the difference of time or duration base maintenance compared to condition based maintenance. The red line in the first diagram (figure 9) shows the point of repair or change of spare parts by a predefined plan. The blue bars represent the life time of a part. When the end of the blue bar is reached the specific part will break down. That means, that for some parts the ware margin is not reached and they are substituted too early and so potential is wasted. Other parts failure before the planned repair and so they will cause unplanned maintenance activities which should be avoided.

The second figure (figure 10) shows condition based maintenance. There the red dots stand for the point of repair or replacement of the part. The blue represents the end of life time of the part. The best point in time to replace the part is close to the point of breakdown (no loss of ware margin, no unplanned maintenance).

All this facts strengthen the need of condition based maintenance.

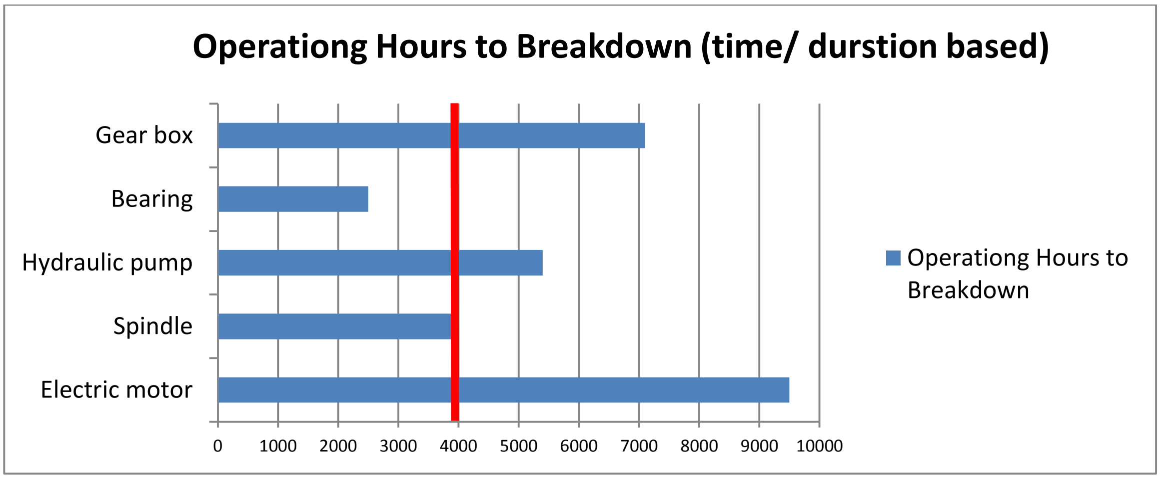

Figure 9: Ware margin and break down at time/duration based maintenance

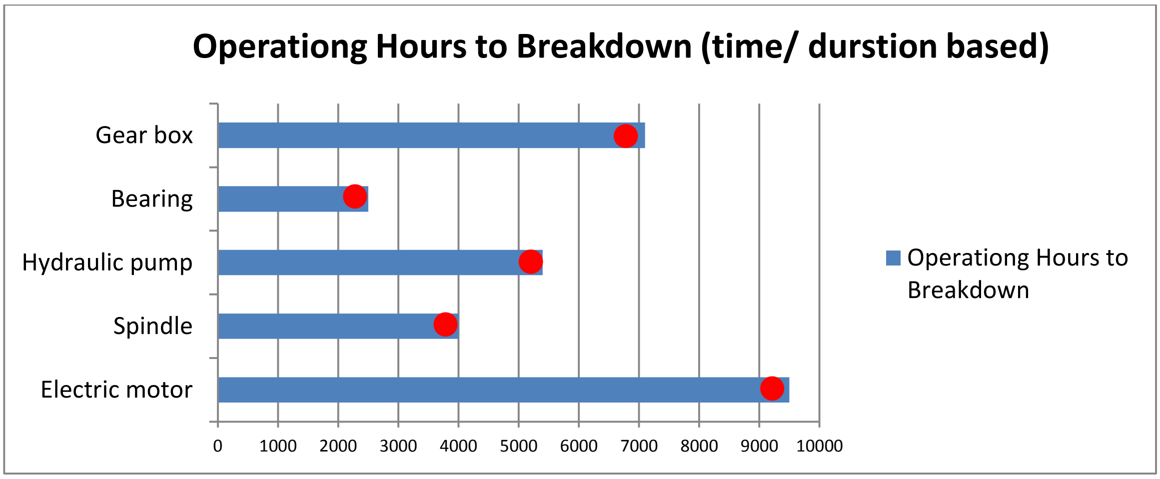

Figure 10: Ware margin and break down at condition based maintenance

2.4 TPM as Maintenance Strategy

Total productive Maintenance (TPM) is a Japanese concept or philosophy. TPM has been developed on the basis of productive maintenance concepts and methodologies. This concept was first introduced by Nippon Denso Co. Ltd. of Japan, a supplier of Toyota Motor Company, Japan in the year 1971. "*TPM is an innovative maintenance approach used to optimize equipment effectiveness, it eliminates breakdowns and promotes autonomous maintenance by involving total workforce"* (Bhadury, 2000).TPM concept is used to maintain the equipment in optimum condition in order to prevent unexpected breakdowns, speed losses, and quality defects occurring from process activities. Zero defects, zero accidents, and zero breakdowns (3Z) are the three ultimate goals of TPM (Nakajima, 1988); (Willmott, 1994); (Noon, et al., 2000)). *"The main goal of a TPM program is to bring maintenance workers and production workers together"* (Labib, 1999)

Total employee involvement, autonomous maintenance by operators, small group activities to improve equipment reliability, maintainability and productivity, and continuous improvement (Kaizen) are the principles given by TPM. A TPM program typically enlarges the responsibility of production employees from operating machines for detecting machine failures, performing basic maintenance, and keeping work areas clean and organized. The basic practices of TPM implementation are often called the pillars or elements of TPM. TPM initiatives, as suggested and promoted by Japan Institute of Plant Maintenance (JIPM), involve an pillar implementation plan that results in a substantial increase in labor productivity, reduction in maintenance costs, and reduced production stoppages and downtimes. (Jain, et al., 1984)

2.4.1 5 Pillars

The TPM strategy is based on five main pillars. These five pillars can be extended by some additional elements like operational assets, cleanliness, order, discipline and work safety. The main characteristic of TPM is the autonomous maintenance that involves everybody in the maintenance process. A short description of the most important characteristics for this investigation is given hereunder. All elements of TPM as they are defined At AHM can be seen in figure 11.

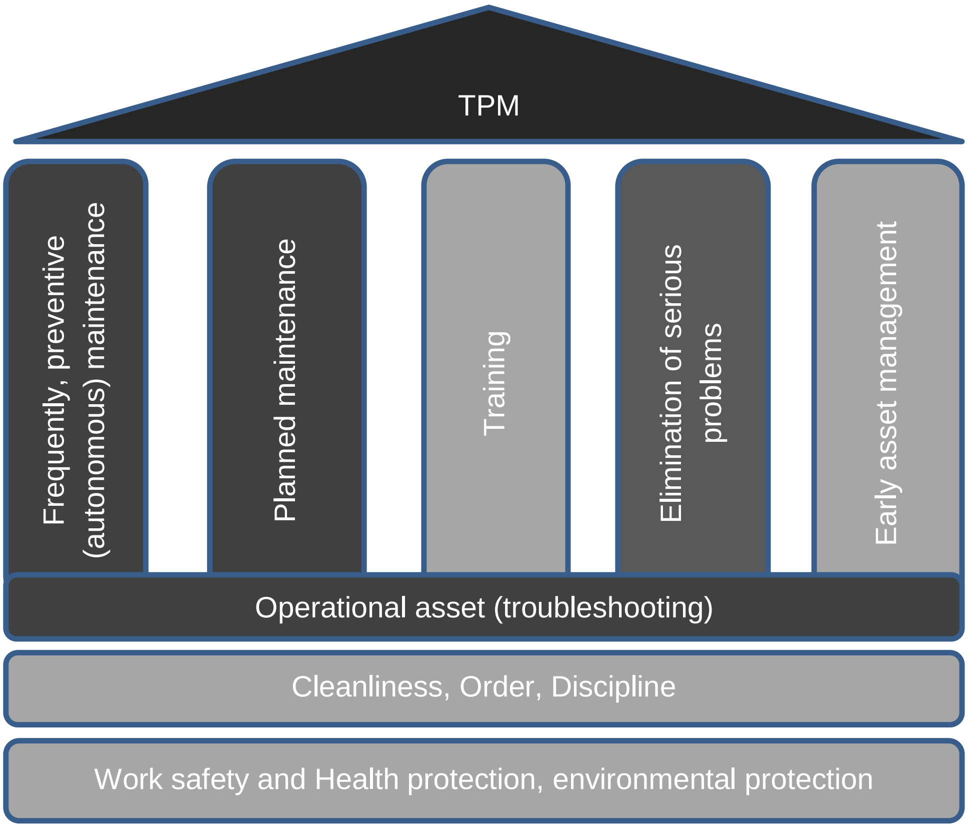

Figure 11: 5 pillars of TPM; modified from Audi internal document

Autonomous Maintenance (JISHU HOZEN)

This pillar is based on the concept that if operators take care of small maintenance tasks it will free the skilled maintenance people to concentrate on more value added activity and technical repairs. The operators are responsible to upkeep their equipment on daily basis to prevent it from deteriorating. The aim is to autonomously maintain the machine to keep it in an optimal condition. The activities involved are of a simple nature like cleaning, lubricating, visual inspection, tightening of loosened bolts etc. Objective of JISHU HOZEN (Autonomous maintenance) are operation of equipment without breakdown, versatile and flexible operators to operate and maintain other equipment and eliminating the defects at source through active employee participation. (Singh, et al., 2013)

Planned Maintenance:

It is aimed to have trouble free machines and equipment without any breakdowns and producing components to the quality level giving total customer satisfaction. Maintenance can be carried out as Preventive Maintenance, Breakdown Maintenance, Corrective Maintenance and Maintenance Prevention. Planned Maintenance is a proactive approach which uses trained maintenance staff to help train the operators to maintain their equipment. Objective of Planned Maintenance are to achieve and sustain availability of machines, optimum maintenance cost, improve reliability and maintainability of machines, zero equipment failure and break down and ensure availability of spares all the time. (Singh, et al., 2013)

Training:
Technologies, methodologies and also the staff are changing continuously. New technologies enter the field very fast. With these changes also maintenance changes. To prepare the employees for the new equipment and new service methods, trainings are important and have to be planned. The trainings can be held by company internal staff or directly by the equipment manufactures. If there is no technology change, the fluctuation in the operating and maintenance staff is a fact which has to be kept in mind. A training program for making the new employees fit to their tasks as fast as possible requires a very flexible organization. (Singh, et al., 2013)

Elimination of Serious Problems:
For improving the equipment efficiency and reducing machine down times, the elimination of frequent and time consuming problems is very important. Equipment failures can be divided in technical failures and operational disturbances. Technical failures consist of breakdowns and preventive maintenance defined by Kuhmonen (1997). The different types of equipment failure can be seen in figure 12.

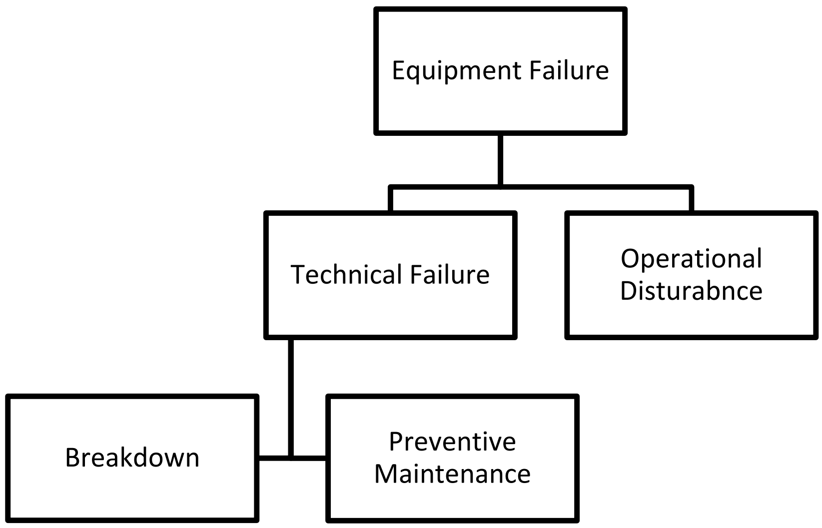

Figure 12: Types of equipment failures; adapted from Kuhmonen (1997)

The main aspects and differences between technical failures and operational disturbances can be seen in figure 13 below. Out of this figure it can be seen, that in most of the cases downtimes of technical failures are far longer than an interrupted production caused by operational disturbances.

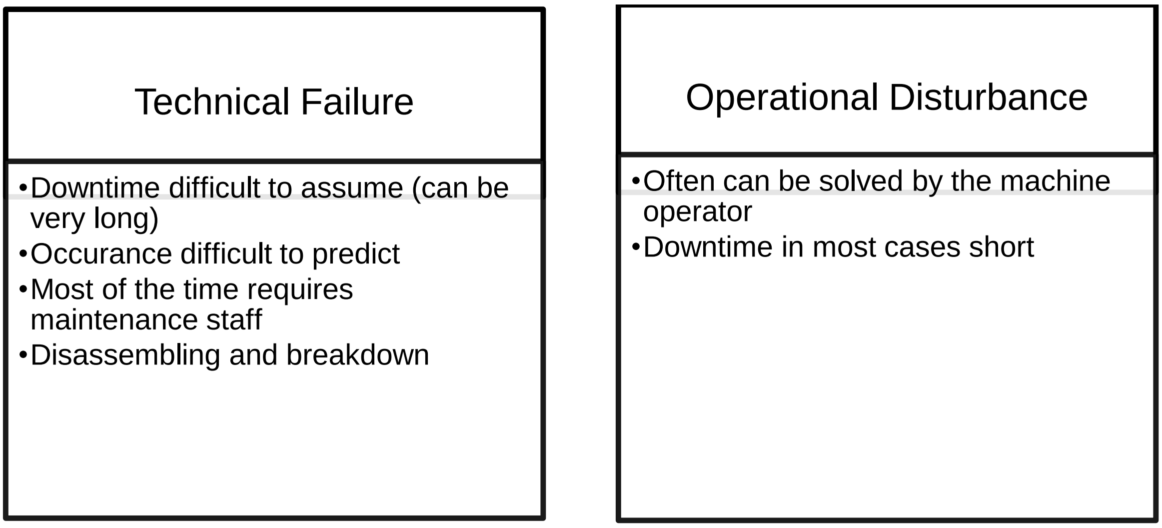

Figure 13: Technical- vs. Operational- failure, modified from Kuhmonen (1997)

Unplanned Maintenance/ Operational Asset
To prevent the production equipment completely from breakdowns is not realistic. Engine failures which lead to breakdowns cannot always be predicted. Therefore it is important to expect breakdowns and have a plan how to react to such events in the best and most efficient way.

2.4.2 Tools

5 S:
“TPM starts with 5S. 5S can be called the foundation stone of TPM implementation. It is a Japanese way of housekeeping. Problems cannot be recognized if the work place is unorganized. Cleaning and organizing the workplace helps to reduce the problems. Making problems visible and identifiable to the employees gives an opportunity of improvement. If this 5S approach is not taken up seriously, then it leads to 5D i.e. Delays, Defects, Dissatisfied customers, Declining profits and Demoralized employees.” (Singh, et al., 2013)

Kaizen:
“Kaizen” literally means “change for the better”. *“Kaizen involves small improvements and is carried out on a continual basis and involving people of all levels in the organization. The principle behind Kaizen is that "a very large number of small improvements are more effective in an organizational environment than a few improvements of large value. This pillar is aimed at reducing losses in the workplace that affect our efficiencies. By using a detailed and thorough procedure we eliminate losses in a systematic method using various Kaizen tools. Objective of Kaizen is achieve and sustain zero loses with respect to minor stops, measurement and adjustments, defects and unavoidable downtime.*” (Singh, et al., 2013)

2.5 Basis Forms of Structural Organization

Sections of maintenance can be organized in different forms. Generally there are 4 basic models (Strunz, 2012):

1. Centralized maintenance
2. Decentralized maintenance
    a. Location- orientated maintenance
    b. Task- orientated maintenance
    c. Object- orientated maintenance
3. Integrated maintenance
4. Maintenance performed by external services

These forms exist more or less in theory and can be observed only rarely in practice in this pure form. In most cases mixed forms of various degrees prevail. In most cases a „central maintenance unit" takes care of the coordination. Different forms of organization may also co-exist. (Strunz, 2012)
Each form of organization shows characteristics, which can roughly be classified into two groups: the first one shows structural characteristics, which includes a number of hierarchy levels, location, allocation of competences (including qualifications); the second one centers on human resources. (Strunz, 2012)

2.5.1 Central Maintenance:

In the past the emphasis lay more on the division of work in production (Taylorism) which resulted in more centrally organized maintenance structures, which were responsible for maintenance in the entire company. There was a strict separation of tasks between production and maintenance. Therefore the workers in production only worked in production, the workers in the maintenance department only did maintenance. (Strunz, 2012)
Centralized maintenance departments were organized strictly in hierarchical levels: management, foreman, assistant foreman and maintenance worker. Depending on the tasks to perform, which could vary according to type of production plant (business), subdivisions can be organized which specialize in different tasks, such as electronics, mechanics, welding, locksmithery, etc. The different maintenance workers do their maintenance work in the different branches in a central repair shop. Centralized maintenance is considered the classic form of organization. (Strunz, 2012)
Essential disadvantages of centrally organized maintenance structures are (Strunz, 2012):

1. Little flexibility
2. High fixed costs
3. Unbalanced and insufficient utilization of human resources
4. Great amount of planning required

Besides, there are high costs of downtime and losses because of long waiting periods for maintenance because of sudden breakdowns of machinery.

2.5.2 Decentralized Maintenance

When enterprises decentralize maintenance they do it for different reasons, mainly for finance and costs, because thus they can avoid losses and economize (Strunz, 2012).

1. Location-orientated Decentralization

Within a production area a maintenance repair shop area is set up which makes it possible to integrate maintenance completely into the production process. The production manager is also the maintenance manager. Maintenance workers become active on demand from the maintenance repair shop which has to provide all necessary specialized craftsmen (electricians, blacksmiths, etc.) for performing the required maintenance tasks.
The difference to the centralized maintenance organizations lies in the necessity of maintenance repair shops having to provide specialized skills. (Strunz, 2012)

2. Object-orientated Decentralization

This form of organization centers on special objects of maintenance. Maintenance repair shops, so-called competence cells, can be organized perfectly for optimal maintenance. Corresponding to the location-orientated decentralization these “competence cells” are operated centrally. (Strunz, 2012)

3. Task-orientated Decentralization

In this case the maintenance worker (a single person or a group) concentrates on specialized tasks, like inspection, oil-change etc. This organization allows to form professional groups, thus planning becomes more efficient. A special characteristic of task-orientated decentralization is increasing effectivity due to the specialization of the workers. There are no different repair shops necessary, just like in the object-orientated decentralization system. (Strunz, 2012)

Comparing the different forms of organizations of decentralization
Using the different types of decentralization potentials in economizing can be gained. As to object- and task-orientated decentralization there are no substantial advantages as to travel time because distances are not shorter. However, due to the special emphasis on object and tasks, advantages in effectivity can be gained because of learning effects. Furthermore, the great knowledge in the asset condition and construction offers to significantly reduce the time required for finding the problem, assembling and disassembling.
In contrast to object- and task-orientated decentralization, the location-orientated decentralization has an advantage of short distances. Since the maintenance worker is in situ there are no unproductive downtimes in case of breakdowns, because of no waiting time for the maintenance worker.
The advantage of maintenance workers specializing in objects or certain tasks limits the spectrum of tasks, but increases the competence of the maintenance workers doing specialized tasks and working on special objects. (Strunz, 2012)

2.5.3 Outsourcing

For companies the right Make-or-Buy decisions within the optimization of the company are vital. In the past years the increasingly broader offer in services, also in maintenance, has brought about a massive growth in competition. This has led to the fact that in recent years maintenance work has been outsourced, because these services are more cost-efficient on the global market. The aim is to reduce fixed costs.
By outsourcing of maintenance tasks the company has to decide in a responsible way: which scopes of functions should remain within the company and which should be outsourced. Costs are the main point of consideration. Aside from that, legal conditions will also influence the decisions.
Within the frame of cost-optimization it has to be considered, if formerly internally performed tasks are to be outsourced. When preparing a decision about outsourcing the question about core competences arises. Outsourcing and spin-offs of some maintenance sections become more important when there are cost benefits. (Strunz, 2012)
Outside services often possess the required competences to fulfill special tasks or they are specialized in working on certain objects. These advantages in competences are used by numerous companies, because they can avoid costly investments and expenses for workers. (Strunz, 2012)

2.6 Process Organization

The organization of work processes include planning, controlling and designing the volume of work, as well as the smooth and accident-free sequences of work, thus regulating the regional and temporal interaction of the use of resources (human resources, machines, materials, auxiliary materials, energy) and the internal communication system in order to fulfill the maintenance tasks. Its operationalization establishes the preconditions for the necessary assessment of rishis and the personalized assignment of tasks. The process organization regulates the description of the workers doing the tasks, their allocation depending on qualifications and the necessary coordination of their interaction. (Strunz, 2012)

3 TPM at AUDI HUNGARUIA MOTOR Kft.

AUDI HUNGARIA MOTOR Kft. (AHM), founded in 1993, over the years became the biggest car engine manufacturer in the world. The production portfolio reaches from four cylinder diesel and gasoline engines to V10 Otto engines. With a production volume of about two million engines per year and roughly 5000 employees, with the number increasing, Audi became one of the largest employers in Hungary too.
The engine production takes place in three main halls which together cover a ground area of roughly 276000 square meters. Beside these main halls for production there is also a huge logistics area for delivering all parts needed at the right time at the right place. The remaining buildings accommodate mainly offices.
On the following pages the structural organization and the layout of the entire engine production are explained. In order to demonstrate the overall size of the plant and the complexity of the production and organization.

3.1 Company Organization

A big company needs a good organization. On the following pages the basic structure of the organization of the car engine production at AHM is explained. Especially for maintenance it is essential to know the organizational structures and the distribution of the production line of the company. Beside the company and the production lines also the TPM process will be discussed; especially how the maintenance sector is organized in terms of structural and process organization and which technologies are used.

3.1.1 Company Layout

In the figure below the floor map of the car engine plant is shown. There are three main production halls. The first and oldest building which is the biggest one, is called G1. G10 is the next behind G1 and the last one is G20, which is the newest and smallest one of these three. Between the halls orange areas are visible. These are logistics areas used to supply the production lines with materials and goods, but also for the engine transport of finished engines to the stock. The huge G12 building belongs to the logistics department too. The purple areas host offices. The G7 building between G1 and G10 contains the Technical service center. For this thesis this area is very important and will be mentioned frequently in the further work. Also located in the G7 building is the operating material storage or spare part storage (Bemi, Betriebsmittellager) which is an important organizational center in spare part handling. Inside the production halls G1, G10 and G20 different colored areas are visible. Areas of the same color belong to the same production segment. (figure 14) The term production segment will be explained next.

Figure 14: Company Layout AHM, AUDI internal document

3.1.2 Production Segment

Each segment is responsible for one specific engine type. At AHM there are six segments. On the plant ground map just five segments are visible. In the real organizational structure there are six segments however. The blue areas (in figure 14) belong to one specific engine type in this specific case, Gasoline engines with four cylinders in a row. Over the years this segment became too big and was split up into two smaller segments. The former G/P4 segment was divided into G/P4 and G/P3. There is a big dynamic within the segment, the number of lines is changing and the produced parts are changing over the years as well. For this thesis it is important to know, that there is no maintenance staff responsible for the whole segment. Either the maintenance is responsible for the whole plant including all production lines or belongs just to one specific production line. In figure 15 the lines belonging to one segment and how they are distributed over the halls can be seen.

Segments:

G/P3 R4 Otto EA 211

G/P4 R4 Otto GE

G/P5 R4 TDI

G/P6 V6 Otto

G/P7 V6 TDI

G/P8 V8, V10

Figure 15: Segment and the lines; modified from AUDI internal document

To get a feeling how the lines of a segment are distributed and which different production lines exist, the lines are listed below. This particular case applies for the G/P5 segment. The number of lines can be different among segments. The G/P5 segment includes lines of all types of engine parts produced at AHM and additionally one engine assembly line.

<u>Five mechanical processing lines:</u>

- ZKG (Zylinderkurbelgehäuse) Engine Block R4 TDI
- ZK (Zylinderkopf) Cylinder Head R4 TDI
- KW (Kurbelwelle) Camshaft R4 TDI
- NW (Nockenwelle) Crankshaft R4 TDI
- PL (Pleuel) Con-rodR4 TDI

<u>One assembly line consists of:</u>

- Sort Engine assembly R4 TDI
- Entire Engine assembly R4 TDI

3.1.3 Production Line

As mentioned above, a segment consists of more different production lines which can be divided into two main groups (mechanical processing and assembly). This is important to know, because from the maintenance point of view the different lines require different amounts of attention. Even the machine types used for production equipment are totally different from mechanical operating lines with lots of high-tech CNC turning, milling and others for machining used facilities. At the assembly lines equipment with a number of sensor pneumatic cylinders and special robotics are in use, therefore the skills of the maintenance personnel has to be different compared to mechanical processing lines.

Machining production Lines:

- ZKG Engine Block
- ZK Cylinder Head
- NW Camshaft
- KW Crankshaft
- PL Con-rod

In figure 16 the production line for the mechanical machining of the V6 and V8 Diesel cylinder block is shown. In order to operate this line roughly 12 machine operators are needed which is a quite small number for more than 120 machines. Inside AHM there is a standard calculation procedure which defines how many people are needed to run one machine. The starting point of production is in the left bottom corner and follows the green line, which represents the conveyer belts. The orange bordered areas are transfer lines (no redundancy between machines). That means the work piece passes through the line and at each station (2B, 3B,) a different process step is performed on the work piece. Contrary to the orange areas there are blue bordered machining centers. Machine center means, that more process steps are performed at the work unit. All those machine centers (BZ1, BZ2, BZ3, BZ4) of one production sequence (AF200) do the same work in parallel (redundant work).
This line is just an example how one single line is built up. Compared to other lines there might be bigger or minor differences, but for the basic understanding of a line it is representative enough.
The visualization of how big the differences in complexity between various lines can be is shown in figure 17. This figure shows the layout of a Con-rod line for R4 gasoline engines.

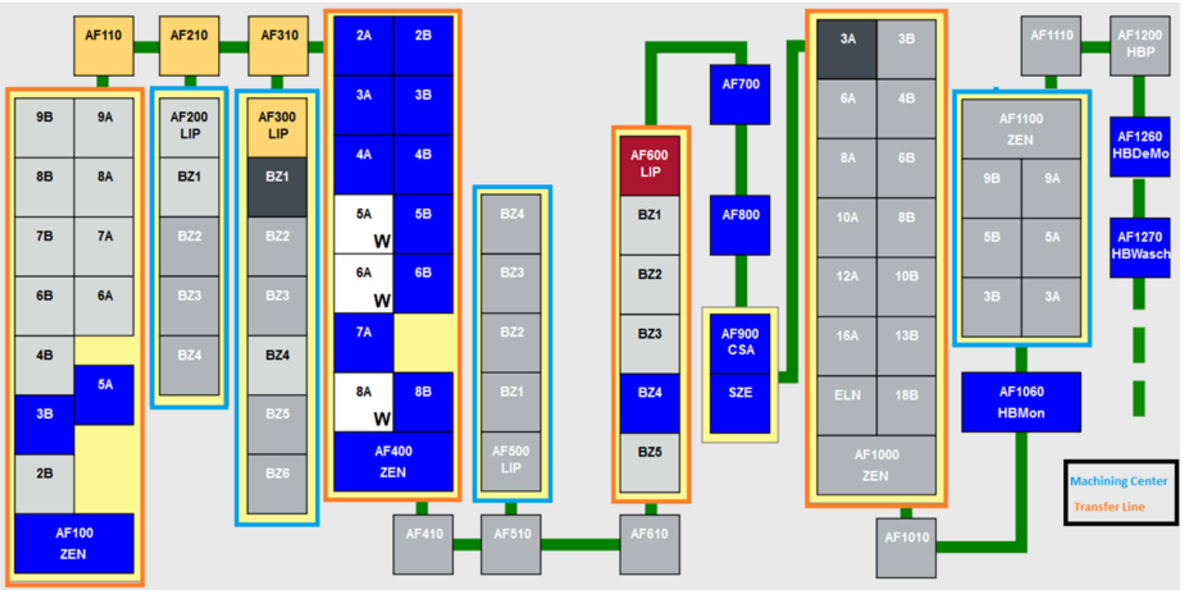

Figure 16: Visualization of a complex mechanical processing production line; AUDI internal document

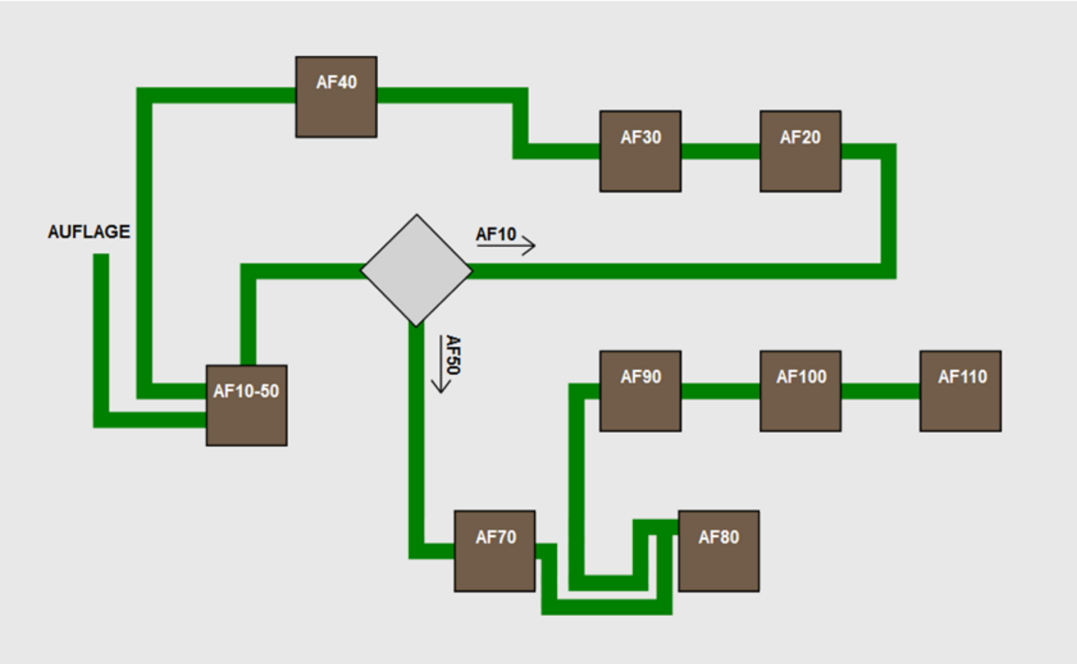

Figure 17: Visualization of a simple mechanical processing production line; AUDI internal document

The different colors for different machines provide information about the operating status of the machine. This information can be very useful for different purposes, but will not be further treated in detail.

Assembly Line:
For maintenance the assembly lines need special treatment. The facilities consist of varios of robotics, pneumatic cylinders with a great number of sensors and a very complex wiring for many work stations. In this thesis the focus of interest is the mechanical processing lines because the required maintenance effort is much higher there.

3.1.4 Machines and Manufacturers

From the approximately 1500[12] manufacturing machines, 1294[13] (the number is increasing) are actually connected to the BDE (Betriebsdatenerfassung, Product Data acquisition) system. In the next year the number will increase, then nearly all of those 1500 machines will be connected to the BDE system. In the entire AHM, distributed over the production lines, machines of many different manufactures are in use. There are also a lot of different types of machines performing their tasks.
Such a huge variety in machine types causes challenges. In the mechanical manufacturing beside complex machining centers and machines for, turning, milling, drilling and grinding there are washing machines, ovens for nitrifying and also equipment for hardening. In addition to these machines, a high number of robots for process automatization are necessary.

[12] Information from Audi internal documents (machines for mechanical processing only)
[13] Calculated from Audi internal documents

It is obvious, that so many different engine types require a very broadly based know-how. Due to the fact, that assets from approximately 54[14] different equipment manufacturers are in use another dimension of complexity evolves.
For robotic maintenance or complex machine parts such as servomotor repair there is a remarkable lack of competences at AHM, and most of these maintenance tasks have to be outsourced for the moment.

Number of production machines	~1500
Machines connected to BDE (Dec.2015)	~1294
Number of machine manufacturers	~54
Number of machine Types	>>54

Table 2: Overview of the production machine complexity

3.2 TPM Management

TPM is the chosen maintenance strategy at AHM. On the following pages, the structural organization and a short description of the main tasks of the people involved, is given, as well as a detailed organizational structure of the involved organizations is described. Materials that are used for planning, carrying out and documenting the maintenance activities, are listed.
The current processes for different events are also visualized and explained on the following pages.

3.2.1 Organizational TPM Structures

The basic organizational structure is shown in figure 18. The left branch of the tree represents the decentralized part of the TPM- or maintenance- organization in general. It consists of the technical service that is responsible for the maintenance of the entire production including all production lines. A detailed explanation of the organizational structure of the technical service will be given later in the thesis. The two right branches represent a mechanical processing and a car engine assembly line of a specific segment. In this case the segment G/P4 which produces the four –in-a row gasoline engine is shown but the basic structure is the same for all other lines too.
Duties and responsibilities of people involved in TPM activities are defined in the TPM manual. For practicing TPM successfully it is essential that everybody involved in the process is aware of his duties and responsibilities. Therefore these job definitions are given.

[14] Calculated from Audi internal documents

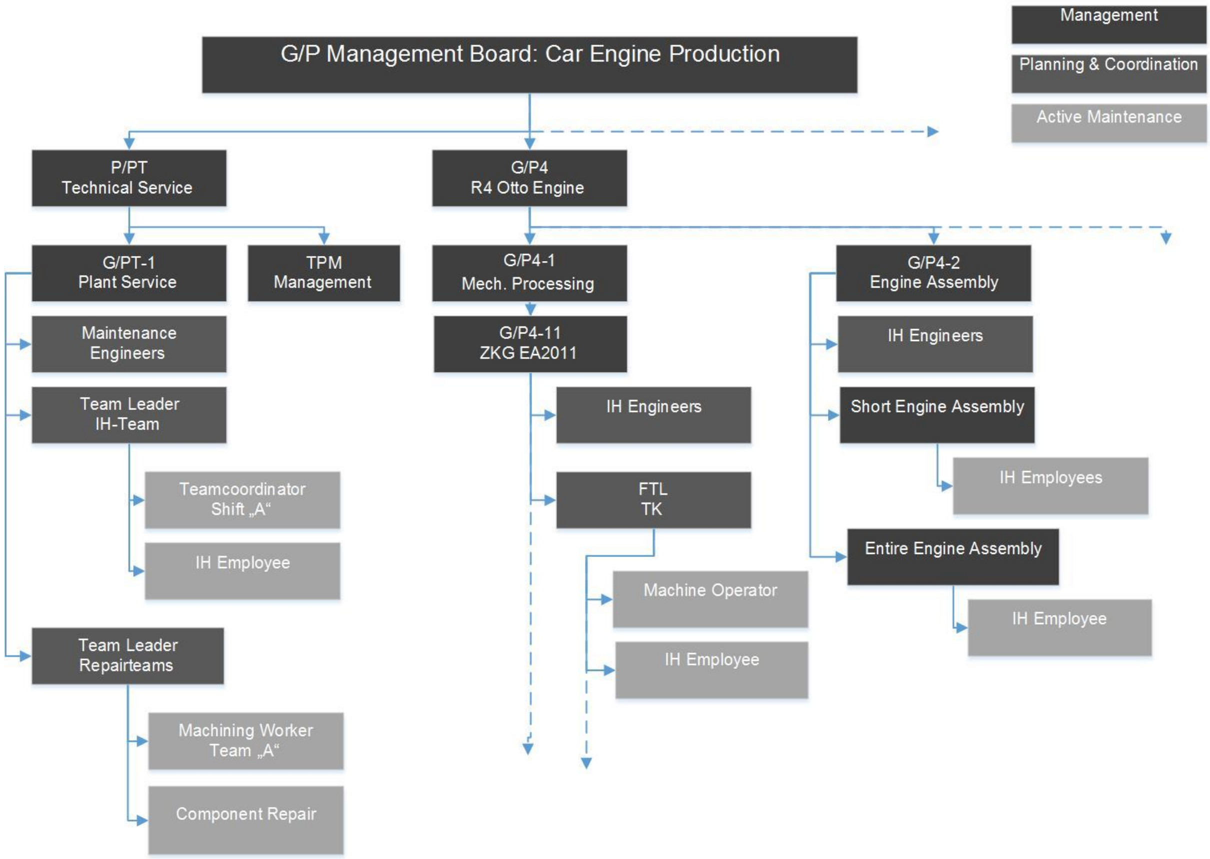

Figure 18: Structural organization AHM, modified from AUDI internal document

TPM Manager[15]: The main task of the TPM-Manager is the continuous development of maintenance strategies within AUDI HUNGARIA MOTOR Kft. as well as giving support for the implementation.
His/ Her functions are restricted to the engine production of Audi AHM.
Further responsibilities:

- Ensuring a up to date TPM user manual
- Involvement in continuous improvements of the TPM-Strategies
- Distributing best practice over the different production segments
- Promoting knowledge transfer
- Methodic support by developing inspection standards and loss analysis
- Supervision of the OEE and preparation of statistics and presentations
- Arrangement of trainings defined during the TPM meeting
- Organization and documentation of the TPM meeting

Head of Plant Service/ Tool Reshaping[16]: The task of the head of the plant service is to support the maintenance strategy defined by Audi AHM. He/ She is responsible for providing services in terms of machine maintenance and machine repair for the entire production.
His/ Her functions are restricted to the engine production of AHM.

Further responsibilities:

[15] Information from AUDI internal documents
[16] Information adapted from AUDI internal documents

- Prioritization of tasks, efficient use of resources considering company targets
- Ensuring human and material resources for maintenance
- Preparation of new techniques and technologies
- Extension of the capacities by including external staff (framework contracts)
- Development of TPM methods

Head of Production (Cost Center Manager)[17]: He/ She is responsible for the reliability of the production process and therefore also for the correct and professional maintenance of the machines. He/ She also has to ensure that the maintenance can be carried out that the conditions for a trouble free maintenance are given. He/ She is responsible for achieving the OEE the quality of the products and economical targets for his/ her organizational unit.
His/ Her functions are restricted to the organizational unit. (Cost center).

Further responsibilities:

- Setting and achieving targets, implement improvements, ensuring their effectiveness
- Human resources and the time frames
- Defining priorities
- Deciding over the inclusion of external staff
- Supervising maintenance activities and costs

Maintenance Engineer[18]: He/ She is responsible for managing the maintenance technically. Planning, organizing and supervising the maintenance tasks at the specific organizational unit are the main tasks of the maintenance engineer. From the planning point of view he/ she is the most important person for maintenance at one specific production line.
His/ Her functions are restricted to the organizational unit. (Cost center).

Further responsibilities are:

- Prepare and develop TPM standards
- Plan and coordinate maintenance activities (planned maintenance)
- Responsible for spare part organization
- Prepare and implement Ad-hoc maintenance activities
- Organize trainings for maintainers and machine operators
- Stay in touch with partners and suppliers
- Prepare documents required for maintenance
- Schedule people for the tasks
- Project coordination
- Check maintenance activities on a random basis, if necessary escalation

[17] Information adapted from AUDI internal documents
[18] Information adapted from AUDI internal documents

Team Coordinator/ Head of Production Team[19]: He/ She has to coordinate the maintenance activities of the employees (responsible for the implementation of the actions). He/ She is responsible for the employees to carry out the activities properly.
His/ Her functions are restricted to the organizational unit. (Cost center)

Further responsibilities:

- Support of a proper implementation of the maintenance work
- Equipment and process optimization
- Organization of trainings for employees
- Failure report

Maintenance Worker[20]: His/ Her work consists of doing maintenance work which has to be done less frequently (quarterly, half-yearly, yearly). Complex planned maintenance activities also belong to his/ her field of responsibilities.
His/ her functions are restricted to the organizational unit. (Cost center)
Further responsibilities:

- Independent implementation of actions defined in the TPM-standards concerning machine maintenance and inspections
- Implementation of planned maintenance activities
- Implementation of unplanned maintenance activities
- Repair engine failures not going beyond his competences
- Change of compact engine parts (ball-screw, hydraulic cylinder…)
- Trainings for production staff
- Optimization of the production equipment and process
- Preparation of maintenance activities
- Attend repair where support is necessary

Production Employee[21]: He/ She has to upkeep the production equipment and to solve minor failures. Giving suggestions for improving the effectivity is one of his/ her functions too.
His/ Her functions are restricted to the organizational unit. (Cost center)

Further responsibilities:

- Cleaning of machines and areas which are assigned to him.
- Independent implementation of actions defined in the TPM-Standard sheets (per shift, per day, weekly, monthly)
- Repair engine failures not going beyond his competences
- Suggestions for maintenance and equipment optimization
- Documentation of the activities
- Documentation of the change of process parameters
- Attending repair where support is necessary

[19] Information adapted from AUDI internal documents
[20] Information adapted from AUDI internal documents
[21] Information from AUDI internal documents

3.2.2 Organizations involved in TPM Activities

All main organizations involved for a proper TMP implementation are listed in figure 19 below. Aside from the TPM manager, the organization consists of two main groups. On the one hand there is a decentralized organization. Therefore each production line has a maintenance organization and staff just responsible for this single production line.
On the other hand there is the centralized organization which basically is the plant service with its different departments, responsible for the entre car engine production.
If the competences or the capacities are not available at AHM some tasks are outsourced to external companies. For maintenance activities where spare parts are needed the spare part storage affects the TPM activities too.

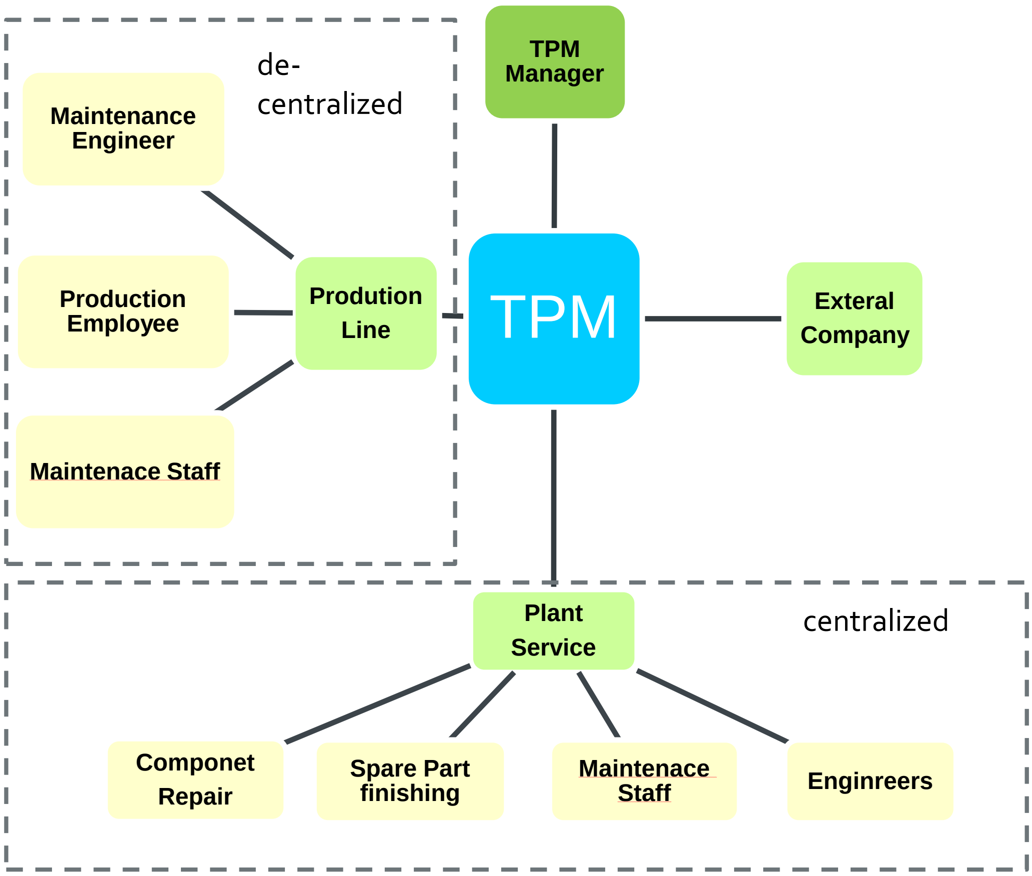

Figure 19: Involved organizations in Total Productive Maintenance (TPM)

3.2.2.1 Decentralized Organization

The following graphic (figure 20) shows the basic structural organization of a production line. The number of Production Team Leader (FTL´s, Fertigungsteamleiter), Team Coordinator (TK, Teamkoordinator,) and Maintenance Employee (IH MA, Instandhaltungsmitarbeiter) for the mechanic processing lines is defined in a so called FMZ sheet (Fertigungsmehrzeit). This FMZ sheet can be seen in the attachment. Within the cylinder-head and engine block lines two maintenance employees are provided while for cam-shaft and con-rod just one person is calculated for maintaining the line in the FMZ sheet (number refers to one shift). The duties and responsibilities of these employees are defined in the job description. The number of electrical and mechanical maintenance engineers can differ a little bit from production line to production line. Generally one mechanical and one electrical maintenance engineer belong to one line. The exposed organigram is from one of the biggest and most complex lines within the entire engine production. This line consists of approximately 130 machines from many different manufacturers.

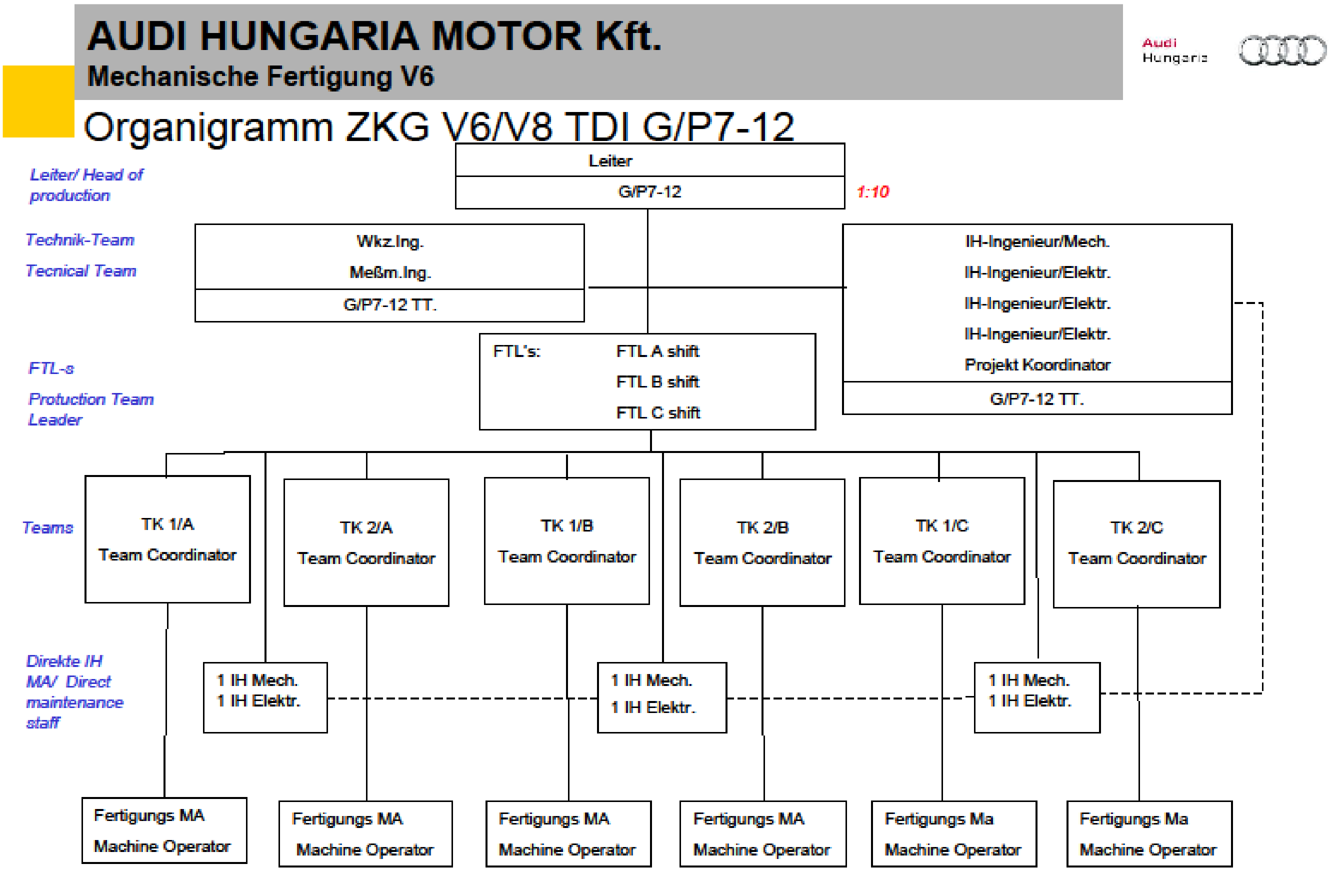

Figure 20: Structural organization of a production line; modified from AUDI internal documents

As mentioned above, the number of maintenance personnel is defined in so called FMZ sheets. The described and permitted number of maintenance staff, production team leader and team coordinators are listed in this sheet. For each class of mechanical processing lines a number is defined.
This is the allocation in theory but in practice the situation is different. On many lines there is a deviation between the target and the current state of employees working at the lines. Considering all mechanical processing lines they are approximately 36 maintenance employees short.

Table 3 shows all mechanical processing lines divided to the segments they belong to. The second column from the left contains information about the line type and the part produced. The third column provides information about the shift model used. The shift model influences the planned TPM activities in particular the TPM shift planning. Therefore this information for the TPM is important. The two numbers behind the slash show how many shifts with how many hours each are done. For example 7/2*12 means seven days production during one week with two shifts twelve hours each. Such production lines are producing around the clock the whole week which makes the TPM activities very difficult.

5/2*8 means five day production with two eight hour shifts. Therefore per each production day, eight hours are left for maintenance activities and two whole days during the week can be used for maintenance. Out of these two different shift models it can be seen that beside the complexity of the line, the shift model of each line has a direct influence on the maintenance activities and the organization. One further influencing variable is, that the shift models depend on the order situation and so the shift modes of the lines can change over the year. The column on the right beside the shift model provides information about how many shifts or shift teams are allocated to the line.

Information about the target number of maintenance personnel per shift and accumulated over the shifts compared to the current amount of maintenance personnel is given. In the last column the difference of how many maintenance staff should be and actually are allocated to the line is shown. Out of this table an overall lack of many maintenance workers can be noticed.

Segment	Line	shift model	Number of shifts (A,B,C,...)	Target IH (FMZ)	Sum targt IH	Real number of IH	Deviation (target and real)
P3	ZK6	6/2*12	3	2	6	6	0
	ZKG	5/2*12	3	2	6	5	-1
	KW	5/2*12	3	2	6	4	-2
	PL Anlauf	5/2*12	3	1	3	3	0
							-3
P4	ZK7	7/2*12	4	2	8	9	1
	ZK9 run up	5/2*12	3	2	0	0	0
	GS	7/2*12	4	2	8	8	0
	EA890	5/1*8	1		0		0
	AVS PN	4/2*12	2	2	4	1	-3
	NW	5/2*12	3	1	3	0	-3
	NS	5/2*12	3	2	6	3	-3
	ZKG	5/2*12	3	2	6	6	0
	NW GW	5/2*12	3	2	6	6	0
	ZKG Flex	5/2*12	3	2	6	8	2
	EA890	5/1*8	1		0		0
	PL	4/2*12	2	1	2	0	-2
	KW1	5/2*12	3	2	6	6	0
	KW2	6/2*12	3	2	6	6	0
							-8
P5	ZK4	5/2*12	3	2	6	4	-2
	PL	7/2*12	4	1	4	0	-4
	IVM R+N	5/2*12	3	1	3	2	-1
	KW	7/2*12	4	2	8	4	-4
	ZKG	5/1*8	1	2	2	3	1
							-10
P6	AVS KoVoMo run up	7/2*12	4	2	0	1	1
	GW V6 V8	5/2*12	3	2	6	2	-4
	ZKG	5/1*8	1	2	2	4	2
	ZKG KoVoMo Anlauf	5/2*12	3	2	0	0	0
	ZK	5/2*12	3	2	6	6	0
	KW	5/1*8	1	2	2	5	3
	ZK KoVOMo run up	5/1*8	1	2	2	0	-2
	AVS KoVOMo NS run up	5/1*8	1	2	2	1	-1
	ZKG KoVOMo run up	6/2*12	3	2	6	0	-6
							-7
P7	ZK	5/2*8	2	2	4	6	2
	NW AVS run up	6/2*12	3	2	6	2	-4
	KW	6/2*12	3	2	6	5	-1
	ZKG	5/2*12	3	2	6	5	-1
							-4
P8	NW	6/2*12	3	1	3	1	-2
	ZK Flex	5/2*8	2	2	4	2	-2
	ZKG	5/2*8	2	2	4	4	0
							-4

Table 3: Shift model and the number of planned vs. real maintenance staff of each production line; AUDI internal document

3.2.2.2 Centralized Organization

The Technical Service is the centralized maintenance organization inside AHM and responsible for the entire engine production including all production lines. The technical service is divided into four parts. Out of these four groups, for this investigation G/PT-1 is of main interest because it performs direct maintenance at the lines but also indirect maintenance in terms of component repair. This part of the Technical Service will be treated in detail on the following pages. Now in figure 21 the overall organizational structure of the Technical Service is shown.

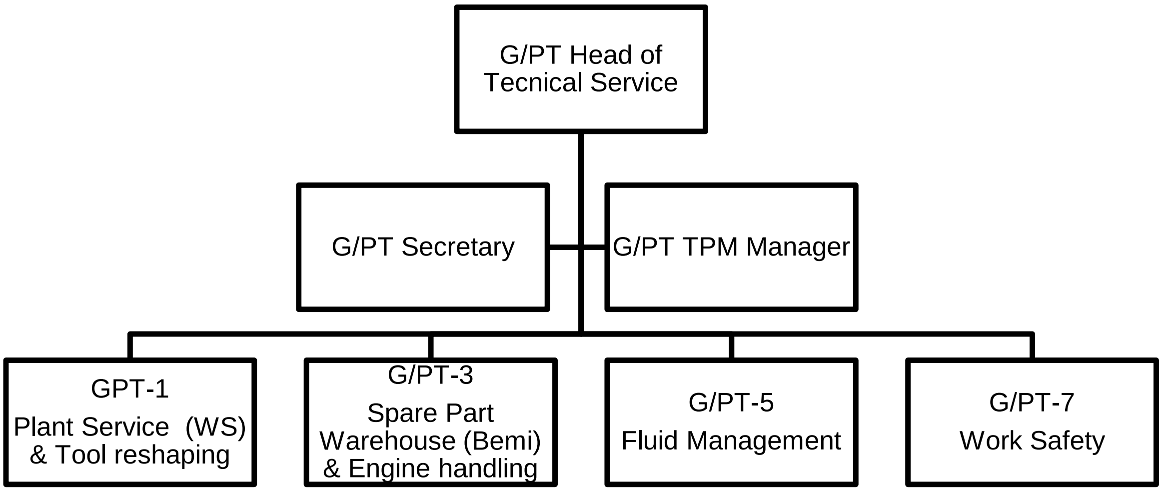

Figure 21: Structural organization of the Technical Service, modified from AUDI internal document

- G/PT Technical Service:
    - Head of Segment
    - Secretary
    - TPM-Manager
- G/PT-1 Plant Service (WS)/ Tool Reshaping
- G/PT-3 pare part storage/ Engine Handling
- G/PT-5 Fluid management
- G/PT-7 Work Safety

The entire Technical Service consists of 112 direct employees and 145 indirect employees. **Indirect** means, that they are directly assigned to the Technical Service and the cost center. **Direct** means, that dependent on the order situation they switch between the Technical Service and the production (lines).
On the next pages the organization and the tasks and responsibilities of the four departments will be shown and explained.

G/PT-1 Technical Service/ Tool Reshaping
The organizational structure of the central Plant Service can be seen in the figure 22. The organization can be divided into three main branches. The left one contains all maintenance and repair activities which are performed for keeping up the production. The column in the middle contains all activities related to tools which are needed in the production. The column

on the right consists of the engineers who do the planning the coordination and give support to the other two branches.

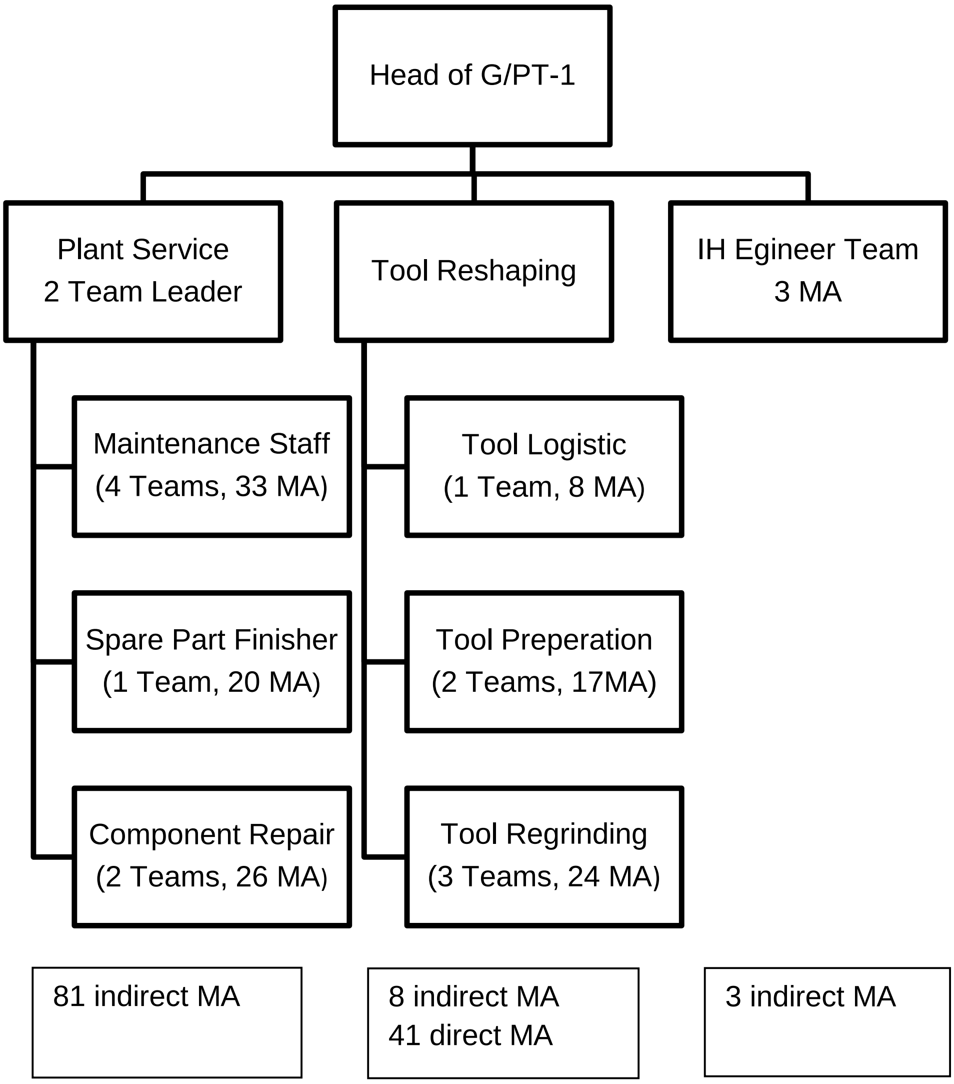

Figure 22: Organizational structure of the Plant Service; adapted from AUDI internal document

Werkservice/ Plant Service[22]: The main coordination of the Plant Service require two team leaders who are responsible for the organization of the work and the coordination of the tasks which have to be done on the different lines all over the plant. Within this thesis when the abbreviation WS is used, the plant service and in particular the maintenance staff is meant.

Team Leader/ Maintenance (IH) Engineers WS:
For doing the staffing and the coordination of the maintenance staff, the spare part finisher´s and the component repair´s two team leaders are responsible. For supporting the team leader and for other projects, three IH engineers are available.

Maintenance Staff: The maintenance staff supports the different production lines to maintain their lines. They go out directly to the lines and give support if needed, for unplanned

[22] Information concerning the Plant Service are derived from AUDI internal documents

maintenance and in break down cases even as for planned maintenance activities. The Maintenance staff is organized in teams and in shifts. Maintenance staff is available 24 hours seven days a week. Thirty-three maintenance workers are divided into four teams (3x8+1x9) which work in two twelve hours shifts.

Spare Part Finisher: They do their work on a shop floor inside the Plant service. They get orders directly from the production lines or from the maintenance staff to produce some spare parts for the production, which have already broken down or will soon do so or which are needed soon. In general, spare parts of minor complexity are manufactured by them. They are not able to produce all spare parts, because the machines needed for production are not available at the shop floor. For example, parts which need a heat treatment have to be produces by an outsourced service provider. The spare part finishing shop floor is occupied around the clock.
In figure 23 the responsibilities of people assigned to the technical service will be presented in figure 23.

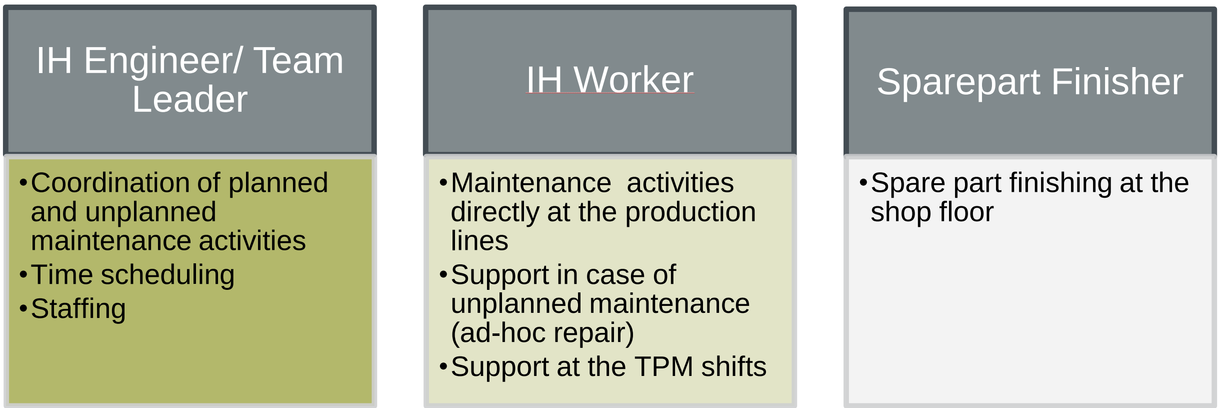

Figure 23: Most important people and responsibilities for TPM

Component Repair: Broken down components like shafts, electric motors, hydraulic cylinders and others are repaired by the component repair staff. Due to the fact, that most of the components are available on stock the components get removed from the engine and substituted by the new one, by the maintenance staff. Then the component will be repaired by the component repair staff and stored at the stock or directly at the line. For the reason, that the broken components can be instantly replaced by the maintenance staff, the Component Repair Staff is not in house all time.
Tool Reshaping[23]: Similar to the Plant Service the coordination for the Tool Reshaping staff is done by two engineers. The main responsibility of this work group is the tool logistic and the tool preparation of the used and worn tools.

Tool logistics: As the name describes, the logistics cares about which tools from which lines have to be treated in which way. Also tool storage is part of this department. Most of the work is not very urgent therefore at night no one of the tool logistics is preset.

Tool Preparation and Tool Regrinding: Used and worn out tools get prepared by the Tool Preparation and Tool Regrinding staff. Tool Preparation is done for milling tools. Replacing and adjusting cutting inserts is the main scope of duties.

[23] Information concerning the Tool Reshaping are derived from AUDI internal documents

Tool regrinding is done mainly for drillers where no parts have to be replaced. The main task is regrinding of the tools to sharpen them for further usage. Due to the enormous amount of milling and drilling tools the shop floor for tool preparation and regrinding is occupied 24 hours seven days a week.

IH Engineers: The three Maintenance Engineers complete the organizational unit Plant Service and Tool Reshaping. Supportive activities for the Team Leader of the Plant Service and the two Team leader of the Tool Reshaping belong to their activities. Furthermore they serve projects like oscillation diagnoses for different lines.

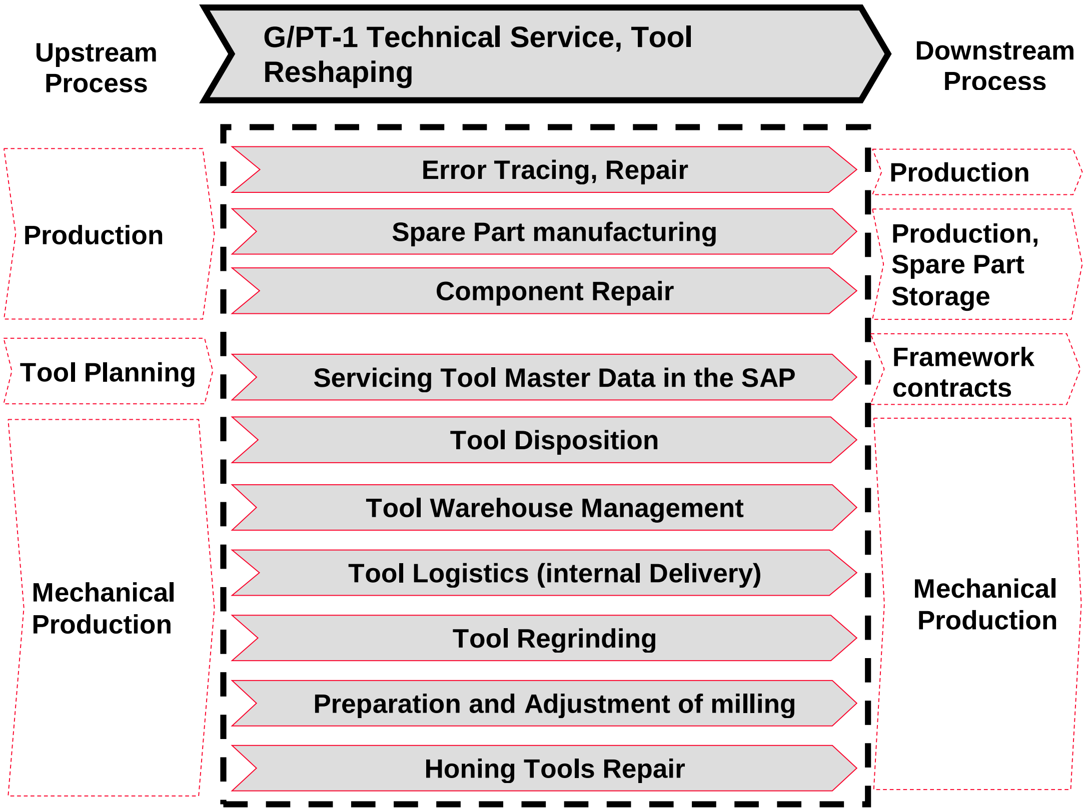

Figure 24: Responsibilities G/PT-1; AUDI internal document

Customer Requirements:

- Fast and proper repair of production equipment
- Supervision of production equipment, repair and maintenance processes
- Tool provision for serial production units
- Participation in reducing maintenance and tool costs

G/PT-3 Spare Part Warehouse (Bemi) and Engine Handling[24]:

This organizational unit is responsible for the Spare Part Warehouse. The spare part storage is a very important institution especially in case of unplanned maintenance where spare parts are needed very urgently. Engine handling and in particular the transport of the finally assembled engines belongs to this organizational unit as well.

[24] Information concerning the Spare Part warehouse and the Engine handling are derived from AUDI internal documents

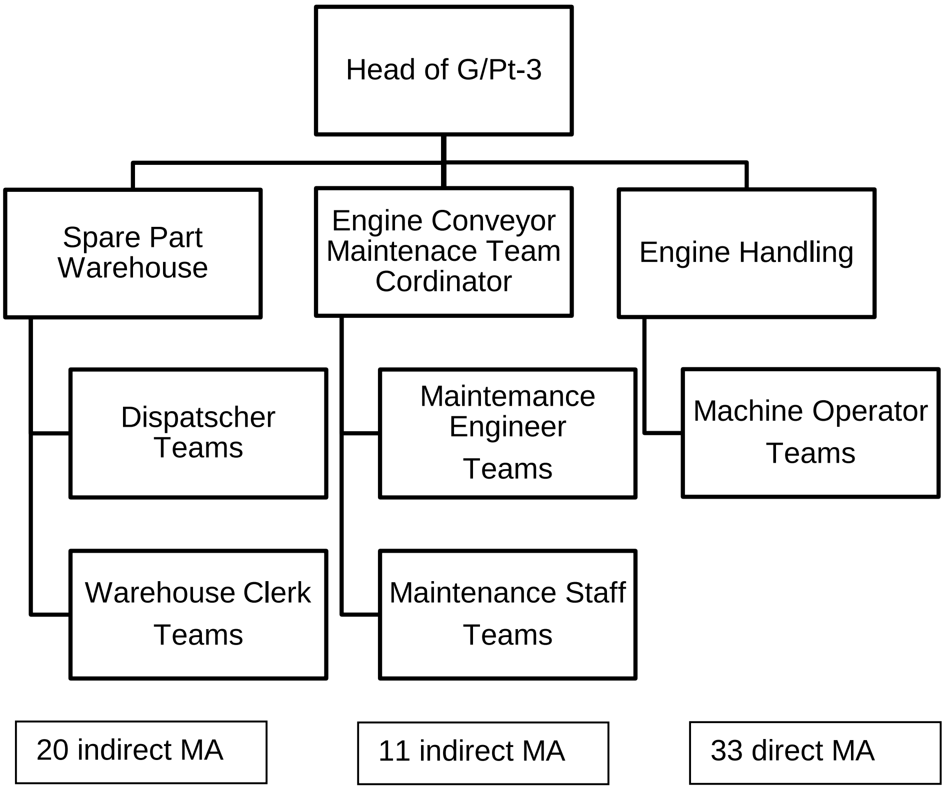

Figure 25: Organizational structure of the Spare Part Warehouse and engine handling; adapted from AUDI internal document

<u>Spare Part Warehouse:</u> All spare parts and operating equipment for the production equipment is available at the Spare Part Warehouse. To run the warehouse, people for purchasing and registering spare parts, as well as employees to hand over the spare parts are necessary. The Spare part Warehouse is open 24 hours, seven days a week.

<u>Engine Conveyor Maintenance Staff:</u> All car engines produced from the assembly lines get transported on conveyer belts of forklifts from the assembly line to the storage. To ensure proper transportation is essential for a well working production, because if the line end is blocked with finished engines new engines cannot be assembled. The task of those employees is to maintain the conveyor to guarantee trouble free transportation.

<u>Engine Handling:</u> This unit contains the conveyor operator.

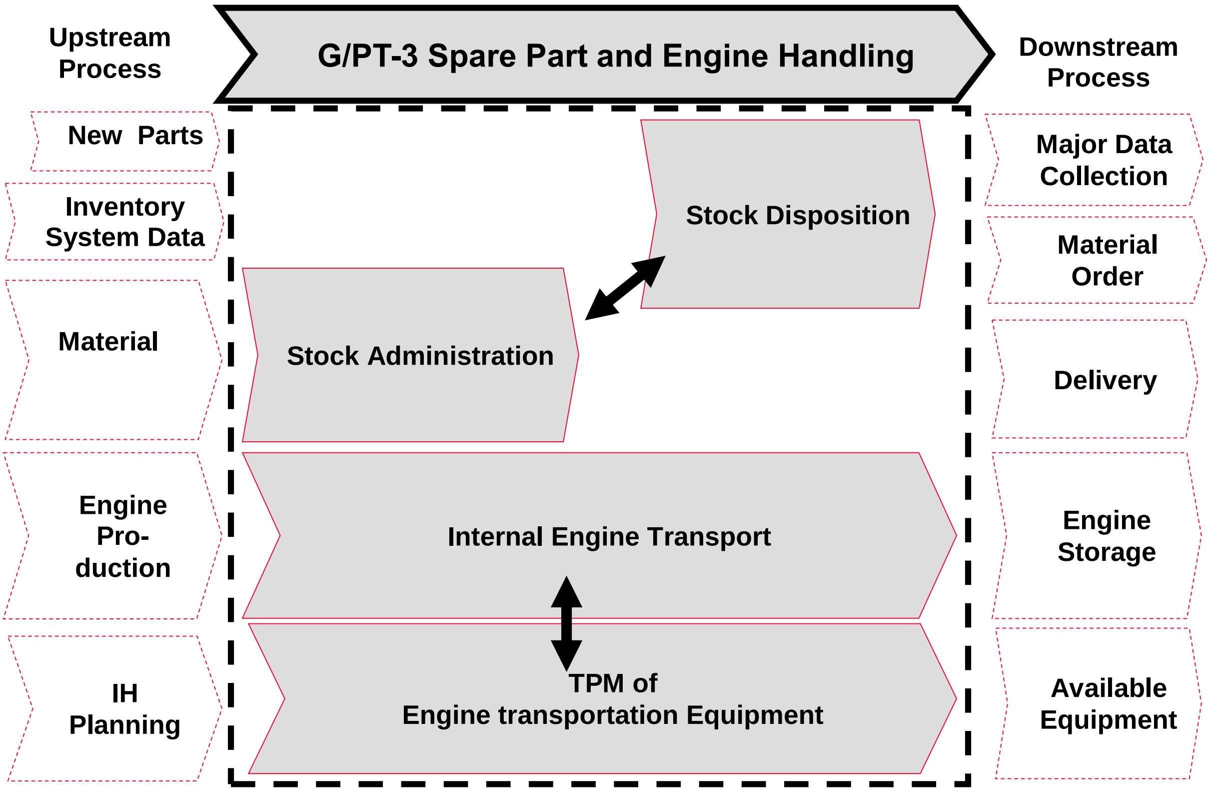

Figure 26: Main tasks of the Spare part Warehouse and engine handling; modified from AUDI internal document

Customer Requirements:

- Ordering of spare parts and processing materials → 100%
- Short waiting time at the issue desk
- No transport damage (engine)
- Available engine transportation equipment

G/PT-5 Fluid Management[25]:

The Fluid Management is responsible for managing the supply of all machines of the entire plant with all needed fluids like coolants and emulsions. The chemical analysis of the fluids is also part of the Fluid Management.

[25] Information concerning the Fluid management are derived from AUDI internal documents

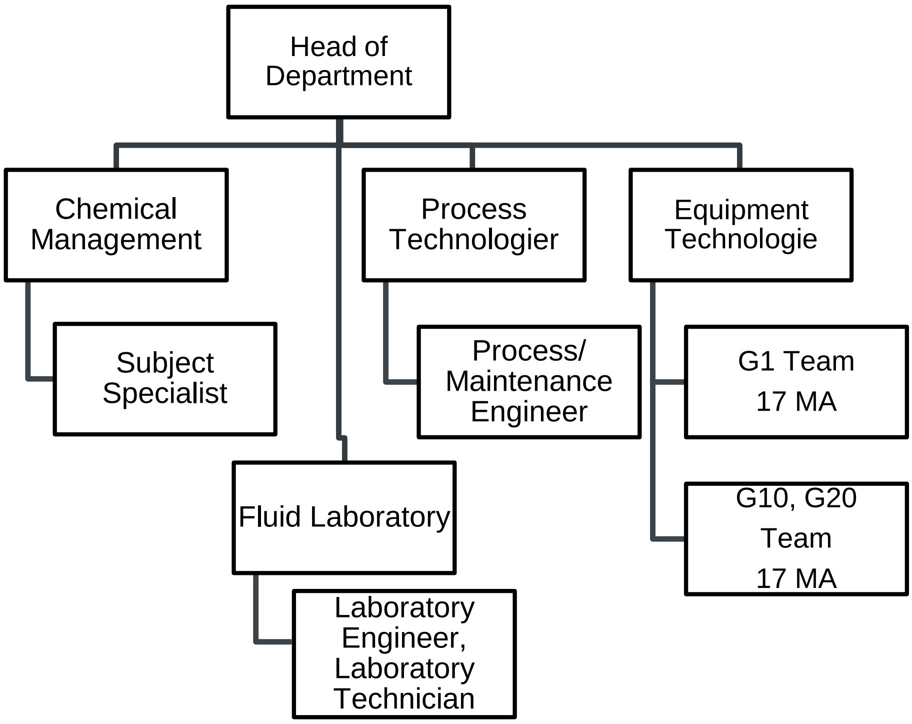

Figure 27: Organizational structure of the Fluid Management; AUDI internal document

G/PT-5 Fluid Management: This organizational unit is responsible for all issues concerning the emulsions at the facilities. All the production equipment is supplied with emulsions from two central stations. To ensure proper emulsion feeding from the center station to the machines and from the equipment back to the central station is part of the tasks of the Fluid Management, as well as the chip transport from the mechanical processing lines to the central collection point is part of the Fluid Management.

3.2.2.3 External Staff

For special maintenance activities where the competences in house are non-existent or if the capacity of human resources is not enough, external companies are employed to support the internal work force. At the moment, external staff is hired for complex maintenance activities such as robot maintenance as awes as for routine maintenance activities. In addition huge frequent inspections of the maintenance equipment are performed by the equipment manufacturer himself.

As to the external staff there are two types of contracts.

<u>Companies with Framework Contracts:</u>

All contract components have already been negotiated. It is predefined how long it may take until the external staff is in house or how long the delivery of ordered spare parts may take. Even the scope and the costs of the services are already predefined. This circumstance makes the whole ordering process easy and fast as well as plannable.

Companies without Framework Contracts:
Sometimes the support of companies where with which predefined contract elements are defined, are needed. In such cases the negotiations about financial terms and the time of implementation are more difficult and time consuming.

3.2.3 TPM Documents

This chapter comprises of documentation and explanations of the most important and most widely used TPM sheets at the mechanical processing lines. At some engine assembly lines the TMP sheets were replaced by a system called WinTPM which is also explained later on in this chapter.

TPM Sheets:
TPM sheets are divided into three main groups. The first one is called “Standard” and contains all basic forms which are needed for performing a viable TPM process. The second one named “Protocol” contains sheets which are used mainly for the documentation of the fulfilled tasks which are specified in the “Standard” sheets. The protocol sheets are needed due to quality reasons. The last main group called “Log book” completes the TPM sheet collection. The “Logbuch” contains all maintenance work and changes performed at the production equipment.

Standard sheets:

- TS01 “Betriebs und Einstelldaten” (Operating and Setting Data)
- TS02 “Wartungs- und Inspektionsstandard” (Maintenance and Inspection Standard)
- TS03 “Service Methoden” (Service Methods)
- TS98 “TPM Blätter” (TPM Sheets)

Protocol sheets:

- TJ02 “Wartungs- und Inspektionsprotokoll” (Maintenance- and Inspection Protocol)
- TJ03 “Wartungs- und Inspektionsprotokoll” (Maintenance- and Inspection Protocol)
- TJ15 “Wartungs- und Inspektionsprotokoll” (Maintenance- and Inspection Protocol)

Logbook sheets:

- TL02 Logbuch (Log book)

TS01: All data for trouble-free operation of the production equipment are listed in this table. This form contains settings for pressure valves, settings for different hydraulic or pneumatic cylinders or oil temperatures. If adaptions are necessary, most of them can be done by the machine operators because they are quite easy to adjust. For supporting the operator and to make sure that the correct values are adjusted, this list is used. How such a sheet for operating and setting standards looks like, can be seen in table 4.

Üzemi és beállítási értékek

Operating and Setting Data

Audi Hungaria

Terület: Bereich:	G/P 7 - 12	TPM lapszám: TPM Blattnummer:	9379 -TS01- 010000	Berendezés: Anlage/AF:	AF100 GM3995/01	Verzió: Version:	1

Sorsz. Lfd.Nr.	What to check?	Where to check?	Set value
1	Szorítás ell. lefuvató nyomás	02B	1,3±0,3 Bar
2	Szorítás ell. Nyomás	02B	1,3±0,3 Bar
3	Zárólevegő mérőrendszer nyomás	02B	0,6±0,3 Bar
4	203-46 Központi kenőrendszer /szakaszos kb.10min/	02B	26 - 32 Bar
5	203-47 Orsókenés nyomás	02B	14-18 Bar
6	203-70/235/240/248/249 Orsókenés hőmérséklete	02B	30 - 38°C
27	203-43/108 levegő kenés	05A	3,6±0,5 Bar
28	Orsó zárólevegő nyomás	05A	1,2±0,2 Bar
29	Szorítás ellenörző vizsgálónyomás	05A	1,2±0,2 Bar
30	Zárólevegő mérőrendszer nyomás	05A	0,5±0,2 Bar

Created by:	Engedélyező: Genehmight:	Érvényesség kezdete: Anfangsgenehmigung:	Lapsz. (Blatt):
		15.05.2015	1 / 2

Table 4: TMP sheet for operating and setting data; Audi internal document

The head line shows the name of the TPM sheet, in this particular case it is the document for the operating- and setting data.

The row under the headline contains further interesting information, in this specific case G/P 7-12 stands for the segment. Seven means (V6 and V8 TDI engines) and 13 is the line number (ZKG). Which kind of TPM sheet is used (TS01) can also be seen on this sheet. AF100 GM3995/01 provides information about the AF (Arbeitsfolge) or operation sequence of one production line, the machine manufacturer (GM: Grob machine) and the project number for this machine. In the right top corner there is a number which represents the version of this sheet. If there are any changes or adaptions done, the version number jumps one digit up. The old versions are stored to make the undertaken changes comparable if necessary. In the bottom row the name of the maintenance engineer, who is responsible for the sheet set up is mentioned. The standard sheet has to be approved and signed by the head of the production line. Then the exact validity date for the standard is shown. In the right bottom corner the number of TPM sheets of this type is mentioned.

Now to the main table and significant information of the operating- and setting data sheet are explained.

In the first column the sequential number is shown, this number will be important for documentation later on. The second column contains a short description of the engine part for which the defined values are relevant. In the third column the specific machine of the particular operation sequence is mentioned. For example the second machine in one operational order has the notation 2B. Letters A and B provide information about the side of the production sequence on which the machine is placed. That designation is necessary for reaching the machine faster and easier. The letter “A” means one the right side in the transfer direction and B means left side in the transfer direction. The fourth and last column shows the settings which are specified. In this column the reference value and a plus minus tolerance for these values are specified.

TS02: For the current TPM this sheet is the most important one, because it defines the different inspection intervals and activities. This sheet is used by all lines in the entire company. The main purpose of this document to identify which kind of inspection has to be done when and by whom. Roughly all inspections which have to be done by each shift per day or per week and even per month are carried out by the machine operator, inspections which have to be done less frequently like quarterly, half yearly or yearly are carried out by the maintenance staff assigned to the specific lines. An example for a maintenance and inspection standard how they are stored at the production equipment can be seen in table 5.

Gépápolási és gépvizsgálati standard Audi Hungaria

Maintenance and Inspection Standard

Terület: Bereich:	G/P 7 - 12	TPM lapszám: TPM Blattnummer:	9379 - TS02 - 010000	Berendezés: Anlage/AF:	AF100 GM3995/01	Verzió: Version:	1

Tevékenység sz. Tätigkeits Nr.	Gépápolási és vizsgálati tevékenységek leírása Service and Inspections	(min) duration	Időszakok / Zeitpanne per shift	daily	weekly	monthly	1/4year	1/2year	yearly	Megjegyzés Bemerkung
1	Gép és környékének tisztítása	40'	X							
2	Sűrített levegő szűrő szennyezettség ellenőrzése	1'		X						
3	Munkatér tisztítása	60'			X					
4	A nagynyomású hűtő és kenőfolyadék-ellátó szerelvényeinek ellenőrzése	15'			X					
5	Nyomólevegő tartály kondenzvíz leeresztése	2'			X					
6	Hűtőközeg szintjének ellenőrzése	2'			X					
7	Paraméterek, beállítási értékek ellenőrzése	30'			X					
8	Körasztalok olajszintellenőrzése	15'				X				
9	Olajszint ellenőrzése az orsó szekrényekben	30'				X				
10	A kenőszerelvények ellenőrzése, kenőtartályok feltöltése	30'				X				
11	A keringetett olajkenés ellenőrzése az orsószekrényekben	15'				X				
12	Védőablakok és védőburkolatok ellenőrzése	60'				X				

Készítette: Erstellt von:	Engedélyező: Genehmigt:	Érvényesség kezdete: Anfangsgenehmigung:	Lapsz: Blatt:
		03.08.2015	1 / 4

Gépápolási és gépvizsgálati standard Audi Hungaria

Maintenance and Inspection Standard

Terület: Bereich:	G/P 7 - 12	TPM lapszám: TPM Blattnummer:	9379 - TS02 - 010000	Berendezés: Anlage/AF:	AF100 GM3995/01	Verzió: Version:	1

Tevékenység sz. Tätigkeits Nr.	Gépápolási és vizsgálati tevékenységek leírása Service and Inspections	(min) duration	Időszakok / Zeitpanne per shift	daily	weekly	monthly	1/4year	1/2year	yearly	Megjegyzés Bemerkung
37	A lineáris vezetékek átnézése sérülés szempontjából	75'							X	
U.	Környezetvédelem (minden fenti pontra érvényes)									
	Összesen:	Σ	40'	1'	109'	150'	350'	100'	460'	

Table 5: Maintenance Standards; AUDI internal document

The head and the bottom row are filled with exactly the same information as the TS01 sheet. Column one on the left side of the main table includes the operation number which will become important in the protocol sheets and the service method sheet. This number is needed for assigning a specific task to a specific number. The inspection task is described shortly in column number two from the right side. Which tasks have to be carried out can be found there, more detailed information are provided by the sheet “Service Methods”. On the right side of the document, a type of a matrix is shown. The column with the numbers right from the task description contains the calculated or predefined duration in minutes for the inspection. The duration is calculated by the maintenance engineer and can be adapted if necessary. This time period stretches from one minute for minor inspections to several hours for major annual inspections. The interval how often the inspections have to be carried out, is mentioned in the axis of abscissae in the matrix. These intervals vary from inspections per shift to daily, weekly, monthly, quarterly and half yearly to yearly inspections. The crosses in the matrix define the specific intervals of inspection. Finally the last row shows the sum of the different inspection durations separated by intervals.

TS03: This sheet named Service methods (table 6) should support the employee to fulfil the required task by providing useful information. In the first column the sequential number which is similar to the number on the Maintenance and Inspection Standard sheet is shown. In the second column, a description of the operation is shown and the method used is also stated. The third column supplies information about what the optimal asset conditions should be like. In the last column a picture is shown to make sure that the task is carried out correctly.

Terület: Bereich:	G/P 7 - 12	**TPM lapszám:** TPM Blattnummer:	9379 -TS03- 020000	**Berendezés:** Anlage / AF:	AF200 LIP GMP200-3995/02-00-50	**Verzió:** Version:	1

Tevék. sz. Tätigkeits Nr.	Service Methods	Opt. Condition	Picture
1.	Gép és környékének tisztítása **Ellenőrzés módja:** Method: A gép és környékének tisztítása, tisztán tartása. A munkát a "Takarítási terv"-nek megfelelően kell elvégezni.		
2.	Pneumatika szűrő állapotának ellenőrzése, kondenzvíz lefúvatása **Ellenőrzés módja:** Method: A gép hátsó ajtaján található pneumatikus szűrőkön található egy-egy szintjelző, amely a kondenzvíz szintjét hivatott jelezni. Ha a leeresztő automatika jól működik nem található a szintjelzőn érdemleges mennyiség, mert a szűrő tartalmaz egy úszót, amit a kondenzvíz emel és ez az úszó működteti a leeresztőszelepet. Ha kondenzvíz szintje emelkedik, akkor azt le lehet csapattatni manuálisan. A szűrőtégely alján lévő kontraanyát felfelé csavarjuk. Így az automatikát kikerülve ürül ki a víz a tégelyből. Ez a rendszer üzemeltetéséhez fontos. Az elszennyeződött szűrőbetéteket szükség esetén cserélni kell! FIGYELEM!!! Csere csak a gép megállítása és a bejövő levegő elzárása után lehetséges!!		
3.	Ki- és lefúvatási funkciók ellenörzése **Ellenőrzés módja:** Method: Működés közben megfigyeljük, hogy a főorsóból (szerszámon keresztül illetve körülötte) áramlik-e a hűtővíz, valamint szerszámcserekor a levegőfúvás észlelhető-e. Ha a funkciók nem megfelelően működnek a berendezést csak a hibák helyreállítása után lehet használni.		

Table 6: Service methods TPM sheet; AUDI internal document

TS 98: This sheet provides an overview over all TPM sheets which are used for one specific operation sequence in one production line. The sheets are listed with the acronyms like TS01 as well as with the name of his use TPM sheet, for TS01 Operating- and Setting Data for example.

TJ02/ TJ03: These sheets are needed for the documentation of the carried out autonomous maintenance actions (table 7).

This protocol sheet is needed for supervising and documenting the TPM tasks. Column number one on the left side shows the date of the day in the current month. The column to the right is needed to fill in the number of the inspection action performed. This number was already mentioned in sheet TS02 where the description of the actions to the numbers is given as well. The next three columns are reserved for the signatures of the employee who has performed the inspections. For inspections which have to be carried out by each shift, three columns are designed because this is the maximum number of shifts per day. There are two further tables on the right side. They are structured likewise the first table, with the difference that there is just one column for signing and the other one is for showing the shift which has performed the inspection.

Gépápolási és gépvizsgálati jegyzőkönyv Audi Hungaria

Maintenance- and Inspection Protocol

Terület: Bereich:	G/P 7 / 12	TPM lapszám: TPM Blattnummer:	9379 -TJ02- 010000	Berendezés: Anlage / AF:	AF100 GM3995/01	Év,hónap Jahr,Monat:	2014 december

Műszakonkénti tevékenységek per shift					Napi tevékenységek daily				Heti tevékenységek weekly			
Dátum	Tevékenység száma Tätigkeits-Nr.	Aláírás Signature	Aláírás	Aláírás	Dátum	Tevékenyseg száma Tätigkeits-Nr.	Aláírás Signature	Műszak Schicht	Dátum	Tevékenyseg száma Tätigkeits-Nr	Aláírás Signature	Műszak Schicht
1					1				1			
2					2				2			
3					3				3			
4					4				4			
5					5				5			
6					6				6			
7					7				7			
8					8				8			
9					9				9			
10					10				10			
11					11				11			
12					12				12			
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24					24				24			
25					25				25			
26					26				26			
27					27				27			
28					28				28			
29					29				29			
30					30				30			
31					31				31			

Havi tevékenységek monatliche Tätigkeiten	Dátum Datum	Tevékenység száma: Tätigkeits-Nr	Aláírás Unterschrift	Műszak Schicht

Table 7: Protocol for carried out TPM activities; AUDI internal document

TJ15: This sheet has the same purpose as TJ02 and TJ03 to record in writing when and by whom the inspections were carried out. This TPM protocol sheet contains the same information as the two explained above, it is only structured differently.

TL02: The log book always refers to one work sequence like the other TPM sheets. All maintenance actions which are planned or unplanned done at one machine are documented in this sheet.

TPM Sheets used in the mechanical processing Lines:

These are the most important sheets which are used by TPM in the mechanical processing lines. Most of them have already been explained. On the following sheet all mechanical processing lines are arranged according to the produced engine part (cylinder block ZKG, cylinder head ZK, con-rod PL, crank shaft KW and camshaft NW) and shown which TPM sheets are currently in use.

As table 8 shows, there are currently many more TPM sheets in use than explained. The matrix above consists of twenty-one different TPM sheets. Many of them like TJ05 and TJ06, which are used for the documentation of the oil fill level, became unnecessary because most of the machines are equipped with sensors for fill level control. Therefore, these TPM documents are not dealt with in this paper because they have a minor influence TPM organization and procedures.

Audi
Vorsprung durch Technik

Linie		Standard						Protokoll													Logbuch	
		TS01	TS02	TS03	TS05	TS98	TS99	TJ01	TJ02	TJ03	TJ04	TJ05	TJ06	TJ07	TJ08	TJ11	TJ12	TJ15	TJ21	TJ22	TL01	TL02
G/P5-12 **P5**	9133 NW CR LeanLine	✓	✓		✓	✓	✓	✓	✓	✓		✓									✓	✓
G/P4-54 **P4**	9124 NW FSI R4 /G10/	✓	✓		✓	✓	✓		✓	✓		✓	✓							✓		
G/P6-41 **P6**	9126 NW AVS Nockenstück CCL	✓	✓		✓	✓	✓				✓	✓		✓				✓				✓
G/P6-42 **P6**	9128 Pumpenocke NW AVS Grundwelle	✓	✓								✓	✓		✓				✓				✓
G/P6-43 **P6**	9132 NW AVS V6-V8 GW	✓	✓								✓	✓		✓				✓				✓
G/P8-13 **P8**	9104 NW 2 (V6, V8, V10) /G1/	✓	✓		✓	✓	✓				✓	✓		✓				✓				✓
G/P5-17 **P5**	9211 R4 KW /G1/	✓	✓		✓	✓	✓		✓	✓		✓	✓									
G/P6-11 **G/P6**	9376 V6 FSI KW /G10/	✓	✓		✓	✓	✓		✓	✓		✓										✓
G/P4-51 **P4**	9214 GE KW R4 Lin1/G10/	✓	✓		✓	✓	✓		✓	✓		✓	✓							✓		
G/P4-52 **P4**	9215 GE KW R4 Lin2/G10/	✓	✓		✓	✓	✓		✓	✓		✓	✓							✓		
G/P4-53 **P4**	KW R4 Otto EA211	✓	✓		✓	✓	✓		✓	✓		✓	✓							✓		
G/P5-14 **P5**	9122 ZK 4 CR /G10/	✓	✓		✓			✓	✓	✓					✓		✓					✓
G/P4-16 **P4**	9101 ZK 6 /G1/	✓	✓		✓	✓	✓		✓	✓		✓	✓							✓		
G/P7-13 **P7**	9111 ZK V6 TDI /G1/ GEN2	✓	✓		✓	✓			✓	✓							✓					
G/P6-13 **P6**	9368 ZK 5 (V6 FSI)	✓	✓		✓		✓		✓	✓		✓					✓					✓
G/P8-12 **P8**	9121 ZK 3 FLEX (V8-V10) /G10/	✓	✓			✓			✓	✓							✓					
G/P4-18 **P4**	9103 ZK 7 /G1/	✓	✓		✓	✓	✓		✓	✓		✓	✓							✓		
G/P7-12 **P7**	9379 ZKG V6-V8 TDI /G1/	✓	✓	✓	✓	✓		✓	✓	✓												
G/P6-12 **P6**	9315 ZKG V6 Otto (Kette) /G10/	✓	✓		✓	✓			✓	✓		✓					✓					
G/P8-11 **P8**	9331 ZKG V8-V10 Alu /G10/	✓	✓	✓	✓	✓			✓	✓							✓		✓			
G/P4-14 **P4**	9127 GE ZKG /G1/	✓	✓		✓		✓		✓	✓							✓					✓
G/P5-16 **P5**	9213 R4 CR ZKG /G10		✓		✓	✓	✓		✓	✓							✓					
G/P4-55 **P4**	9210 R4 PL OTTO	✓	✓		✓	✓	✓		✓	✓		✓	✓							✓		
G/P5-13 **P5**	9137 PL PD TDI	✓	✓		✓	✓			✓	✓										✓		
G/P4-56 **P4**	R4 PL EA211	✓	✓		✓	✓	✓		✓	✓		✓	✓							✓		

Table 8: Matrix of lines and used TPM sheets; AUDI internal document

Shift Protocol:

This protocol is not part of the TPM sheet collection by definition but is used by most of the lines. This protocol is used by the machine operator who is responsible for one AF (Arbeitsfolge, operating sequence). Hence this document contains all information about the events that occur during one day. The sheet contains information about the object (V6 TDI ZGK) the team working during that day (2A), the date (21.07.2015), the name of the equipment manufacturer (Grob) and the working sequence (AF100). The down time is also documented

in the sheet as well as the quantity and type of units produced. The quantity of parts if needed has to be specially classified in parts which are deemed okay, not okay or scrap.
All incidents that occur on a day are recorded in that protocol. The first column specifies the single machine of the working sequence followed by the starting time and the duration of the incidence. Then the failure code and a short description of what happened is noted. The last two columns contain the actions which were performed in order to solve the problem and the last one is the signature of the employee doing the documentation.
This document is the base for the so called morning meeting. All maintenance engineers, the production team leader and the team coordinator attend this meeting. During this meeting, the top events of the last day documented in the shift protocol are discussed as well as, which actions can or have to be done if one of those problems occurs again. The target of these meetings is to make the production more efficient and reduce down times. An extract of such a shift protocol can be found in the attachment to this thesis.

Win TPM: This Win TPM system is quite similar to the paper standard TPM documents in use. It is mainly used at the engine assembly lines. One reason therefore is, that the complexity of these lines compared to the mechanical operating lines is different and so the maintenance activities are different too. Additionally there are no long work sequences which have to be supervised by one operator like in the cylinder-head, engine block, crankshaft, cam-shaft and con-rod production. At the engine assembly lines there is great number of small machines which require a relatively great amount of labor. However, the biggest difference compared to the conservative system with the sheet is, that the Win TPM system runs on the machine control panel. All sheets are provided in electronic form. For the frequent inspections which have to be done there, a form similar to the TS01 sheet where all inspection and time of implementation are shown, is used and visualized on the machine control panel. The digital system provides automated information about which inspections have to be carried out and when. If the work task is marked yellow it means that the inspection is soon to be carried out. Red means that the deadline for inspection has already passed. The white inspections a task which will be have to be performed in the future.
If one specific task has to be fulfilled, the system provides information related to this task for the machine operator or the maintenance employee who has to accomplish the task by selecting the task by clicking. This information can contain settings for valves or pressures for pumps like in the TS01 TPM sheet. Also information about how the work has to be done is provided by the WinTPM system. This information is similar to the TS03 Service Methods sheet.
After accomplishing an inspection the person, who has done the work, must document the task. Therefore the name of the employee, the ID number and eventually a comment that the inspection was done correctly, is required. Then this task is marked as finished and stored in the system.
This system has two main advantages compared to the traditional system. The first one is, that it is not necessary to find the tasks which have to be accomplished in the TS02 list. In the Win TPM System the tasks are listed by date and the time of implementation is visualized by the traffic light system. The second main advantage is that further information concerning the task, a description, pictures or plans are directly stored related to this one specific task. This procedure saves time and also minimizes failures.

3.2.4 TPM Process Organization

The process organization beside the structural organization is the second main dimension of the TPM organization. Three main processes are defined for carrying out TPM. For autonomous maintenance and planned maintenance but even for unplanned maintenance, action processes are defined. These main processes include several supporting processes like the ordering of spare parts, the hiring of external staff and the WS.

3.2.4.1 Autonomous Maintenance

Autonomous maintenance is a form of frequent and preventive maintenance. Developing a machine specific maintenance plan which is carried out by the machine operator or maintenance staff is the first and most important step for implementing an autonomous maintenance. (TS 02 or WinTPM are the used media)

Goals:

- Ensure the quality of the products
- Ensure machine availability
- Increase the life cycle of the equipment

Activities to carry out by autonomous maintenance:

- Machine cleaning (working area, service area, machine area)
- Machine care (lubricate, filter change, oil change)
- Check and replacement of worn parts

The inspections, specified in this standard will be done by the responsible person autonomously. Who is needed for doing the inspection depends on the complexity of the task and is explained in the description of the TPM sheets in chapter 3.2.3. The figure below (figure 28) reveals how the development of such a TPM standard works. Each engine supplier is required to provide an engine maintenance schedule which suits the existing TPM System of AHM. The preparation of the sheet is the duty of the associated production line and in particular the maintenance engineer of the production line. The head of the production line then has to release the document by signing it. The maintenance engineer also takes responsibility for the correctness of the sheet.

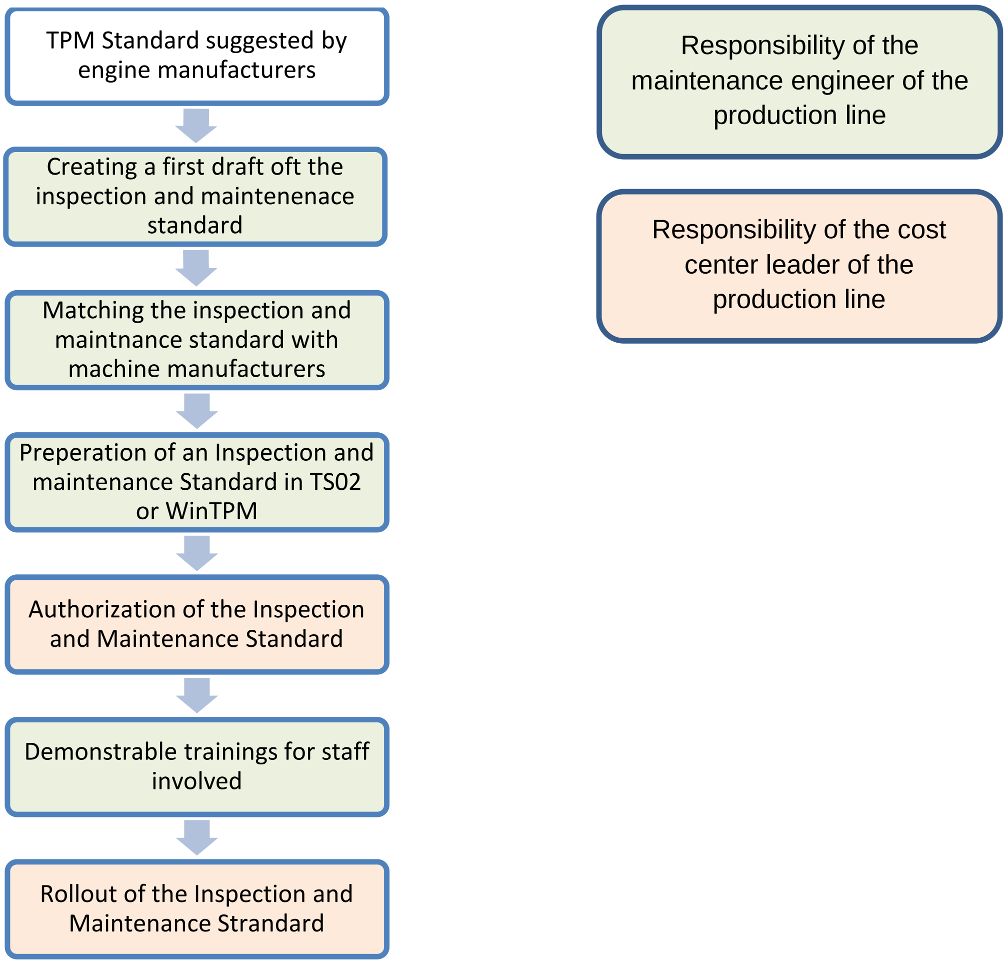

Figure 28: Process for developing a TPM (TS02) standard sheet; modified from AUDI internal documents

At least once a year or if necessary more frequently, the inspection standards have to be reviewed and modified. The validation of the Inspection and maintenance has to be done under consideration of the following aspects.

- Definition of maintenance needs, deviating from quality indicators
- Integration of the experiences collected over the last year (decrease or increase the inspection intervals)
- Checking the balance (reduced down time doe to maintenance)
- Coordinate deletes or changes in the maintenance behavior during the manufacturer warranty
- Share and compare information and experiences with engineers running similar machines

The process of developing a TPM Standard sheet TS02 is shown in the next figure, it is a co-work or cooperation between the head of the cost unit and the responsible maintenance engineer.

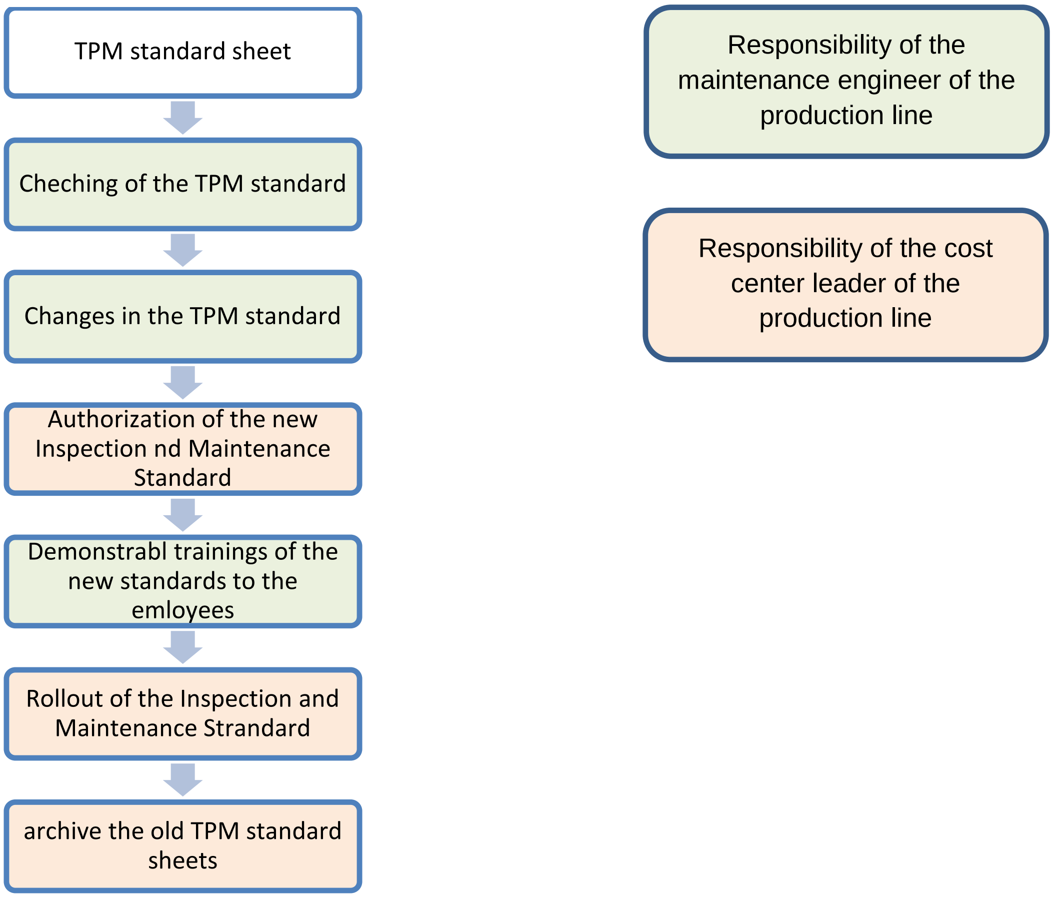

Figure 29: Yearly adaption of the TPM standard; modified from AUDI internal documents

3.2.4.2 Planned Maintenance

Planned maintenance means the implementation of activities for stabilizing the production process and reducing machine failures and break-downs. Furthermore planned maintenance improves the quality of the production and decreases the amount of unplanned maintenance. Most of the engine failures and break-downs need a longer period of time to develop until they become obvious. Through observations, e.g. if unusual sounds or vibrations are detected, future failures can be recognized earlier. Generally it is far cheaper to repair things earlier which might break down soon because planning is easier and it does no take that much time like an unplanned repair does.

The planning and definition of planned maintenance can be based on the following considerations:

Input parameters for planned maintenance[26]:

- Number of operating hours and actions
- Feed-back from employees
- Discovered irregularities during autonomous maintenance
- Development of quality indicators
- Results of equipment diagnosis
- Evaluation of downtimes and loss analysis
- Evaluation of further statistic data
- Experience level of the employee

The maintenance engineer is responsible for planned maintenance actions.
Tasks of the engineer:

- Definition of activities (set up a plan)
- Definition of the performing individuals
    - Line´s own staff
    - Support from the WS
    - External staff
- Provide all materials used (spare parts, technical material, drawings)
- On time planning of implementation (TPM-Shift, parallel to the production...)

Figure 30 below shows how the process for planned maintenance activities looks like and who are the main responsible people for carrying out this action.

[26] Information from Interviews: Input parameters for planned maintenance actions.
Hollósi Gergo Balasz G/P3-13 Line Maintenance Engineer
Gabor Pasci G/P7-13 Line Maintenance Engineer
Karoly Hevesi G/P5 Head of Production Segment
Albert Fazekas G/PT Maintenance Manager

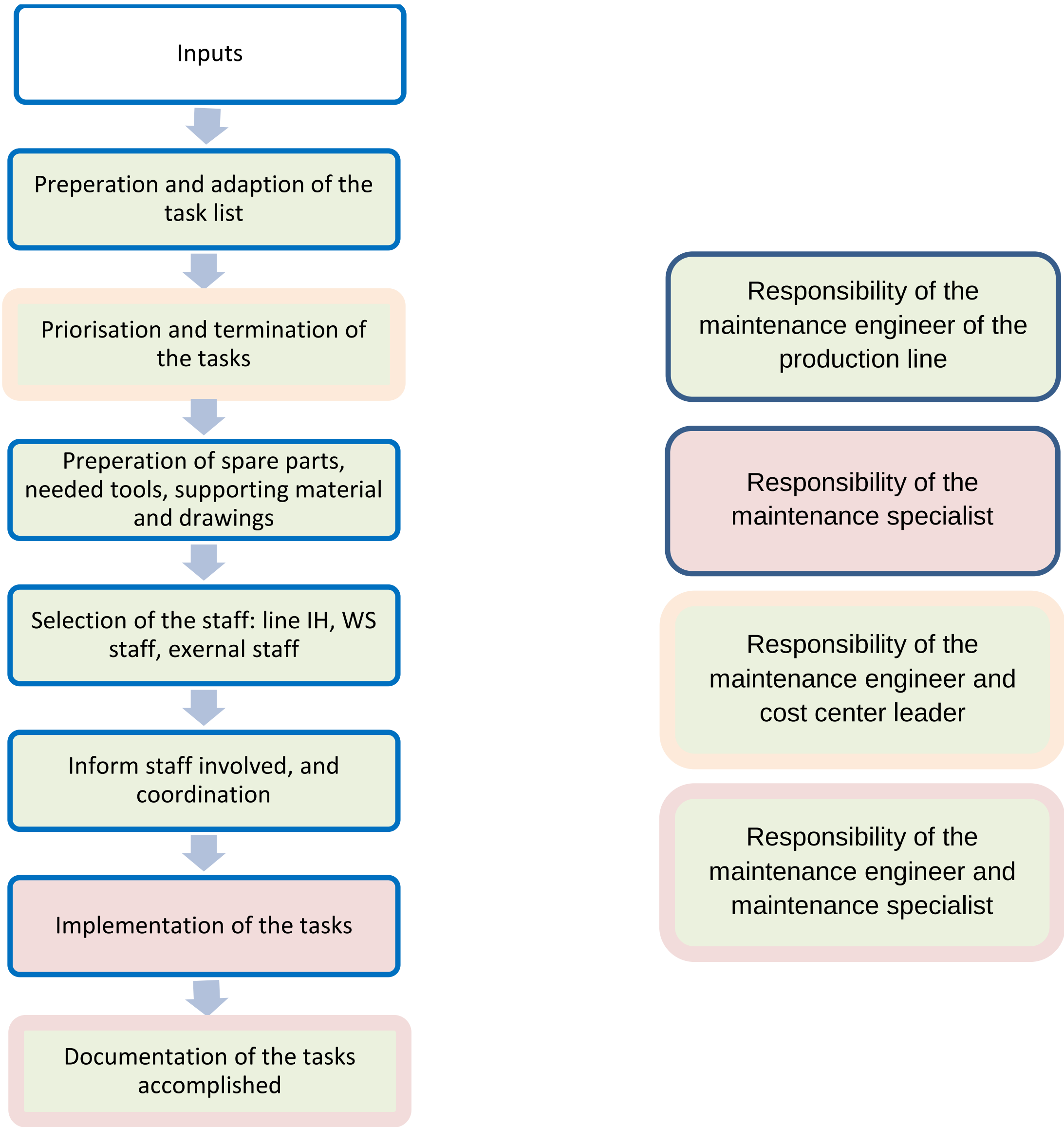

Figure 30: Process for planned maintenance activities; adapted from AUDI internal documents

Generally these planned maintenance tasks are done during the so called TPM shifts of each segment (figure 31). For many maintenance activities, the plant service (WS) or the support by the plant service is needed. To use the resources of the plant service more efficiently, each production segment has TPM shifts on a defined day divided over the whole week. On Monday, segment G/P5-1 has its TPM slot, on Tuesday G/P4-1 has its TPM slot and so on. If these TPM shifts are in practice carried out each week on the lines, depends on the production and shift program and furthermore on the maintenance intensity of the equipment of each single line. Some do TPM shifts weekly, others perform TPM shift just once a month.

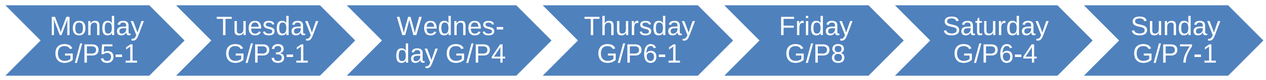

Figure 31: Defined time slots for TPM actions; AUDI internal document

Plant Service Company Holiday Maintenance Plan:
The Plant Service, which is responsible mainly for ad-hoc repairs and for giving support to the TPM shifts, is responsible for planned maintenance during summer and winter shut-down. The procedure how this plan is developed is described next. At first the team coordinator of the plant service sends forms to the different lines where the IH engineers of the specific production field fill in the maintenance tasks which they would like to have accomplished during this period. The IH engineers send the documents back to the Plant Service. The engineer there compares the resources and the orders. Then he has to delete or postpone the tasks. The remaining tasks have to be prioritized if necessary. The final step is to schedule the tasks and allocate the employees to the tasks.

3.2.4.3 Unplanned Maintenance

One of the main targets of TPM is to reduce down times, breakdowns and unplanned maintenance, because as mentioned before unplanned maintenance activities are much more time-consuming and, more expensive. Apart from these negative effects, various other kinds of improvisation also concerning the production are required. To totally exclude break-downs is a non-realistic scenario but should be the target. Therefore it is obvious, that unplanned maintenance activities will occur and have to be dealt with. The process for unplanned maintenance is shown in figure 32 below.

Involved in this process are:

- The **machine operator** who realizes the breakdown first. He/ She tries to solve the problem. If he/ she is able to fix it he is doing the documentation. (shift protocol or the like) If he/ she cannot solve the problem he/ she reports the situation. (usually to the team coordinator, because he/ she is located directly at the line too, and or to the production team leader).
- **Team Coordinator and Production Team Leader (TK and FTL)** are trying to find a solution for the problem. In many cases the IH engineer is already informed. If the IH engineer does not know that there is a problem already, he/ she will be informed by the TK or FTL if they are not able to solve the problem.
- The **Maintenance engineer** is involved in the process and also tries to find a solution for the problem. If he finds a solution and the problem can be fixed by the line IH he will inform the people. Documentation is done after the work is completed. If the plant service (WS) support or external support I needed communication due to the local separation becomes a problem. The WS or external staff receiving the request mainly via the phone calls.
- The **WS team coordinator or engineer** receives the request. The process how these requests are processed is shown in Figure 33.

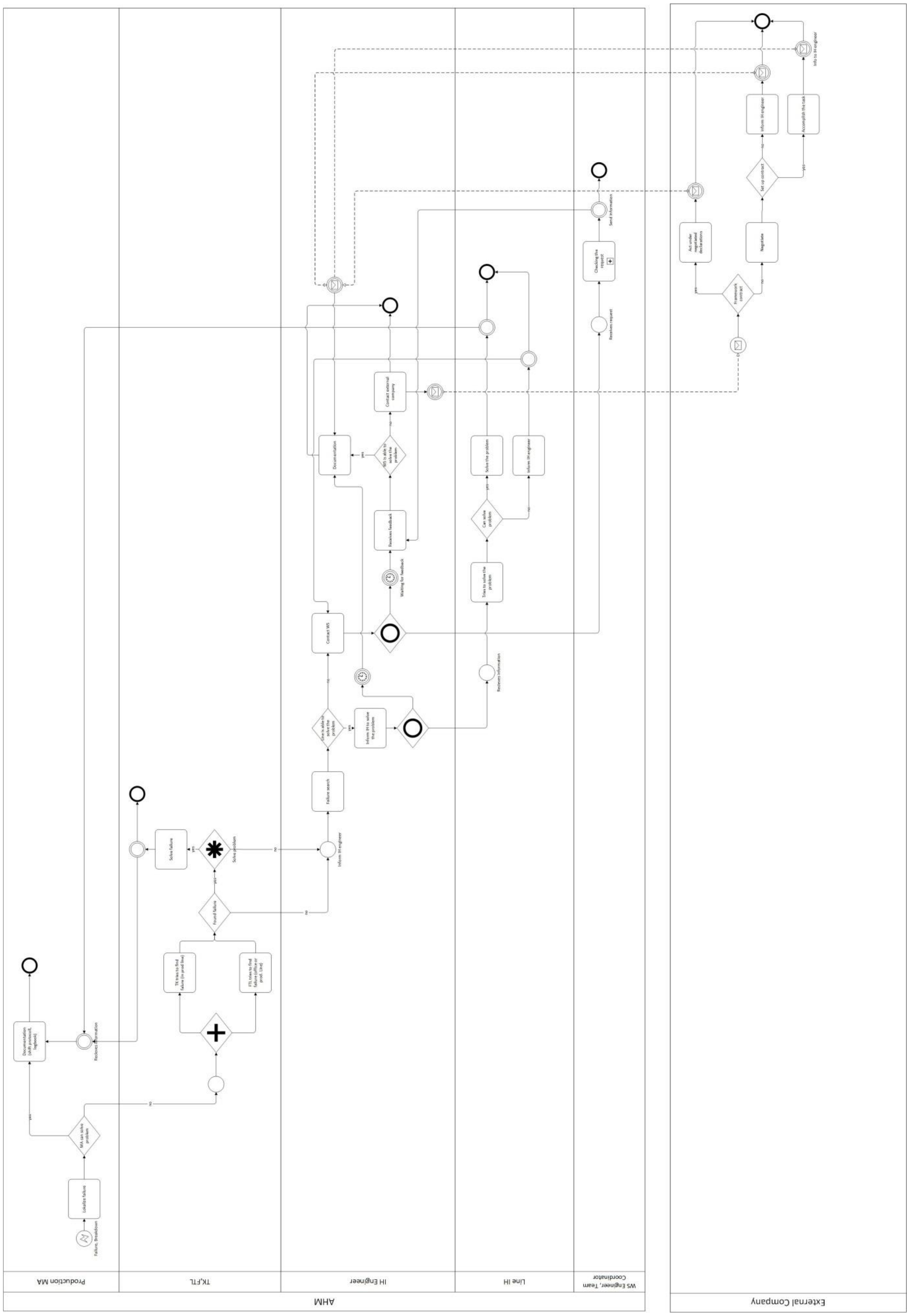

Figure 32: Process for unplanned maintenance activities (entire process)

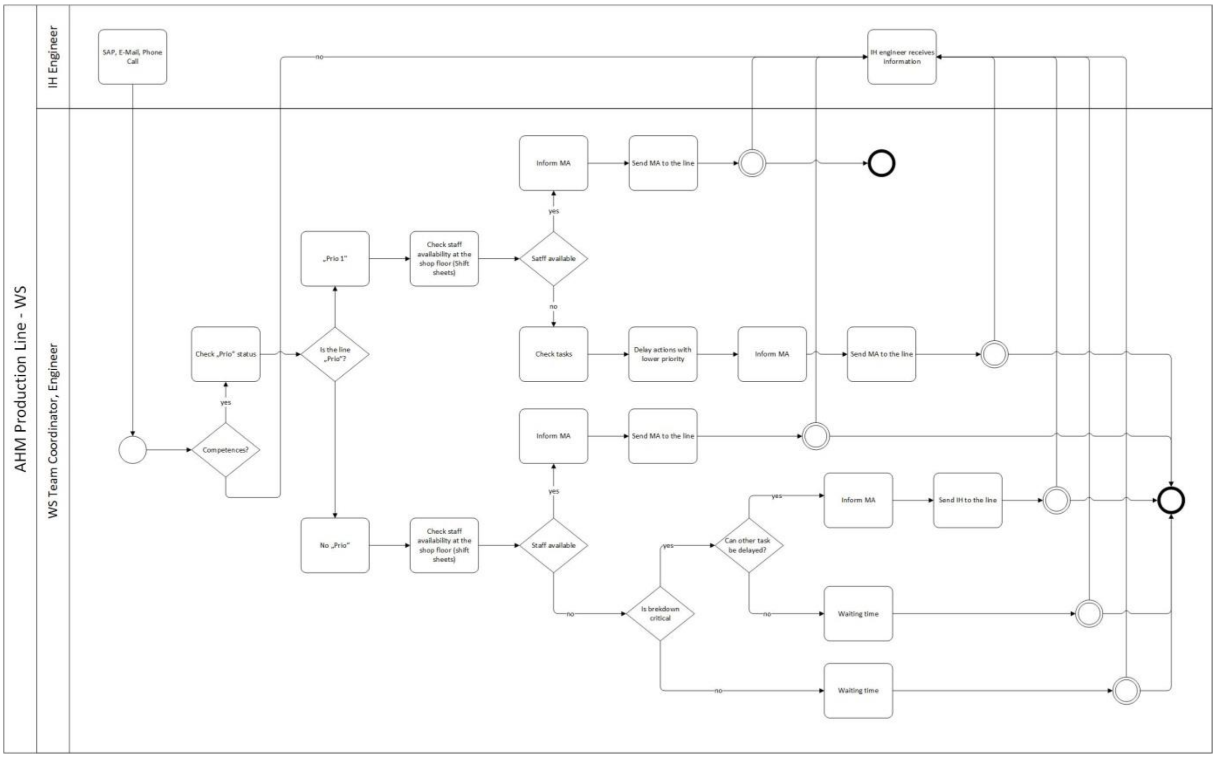

Figure 33: Process for unplanned maintenance activities at the plant service site

What can be gathered from this workflow is the fact, that if the cause of the failure cannot be identified quickly, it takes a long period of time until the right person is at the machine to fix the problem. This period of time where just failure-search and calling for help is done, has to be shortened or avoided in the best way.

In the BPMN chart, the real process for unplanned maintenance cases is shown. In some particular steps the process can be different from production line to production line. First, there is a number of employees involved in this process. Second, a lot of communication is necessary. And the communication mainly takes place via telephone e-mail or verbally. Third, the process is very time consuming. The main workload, with all its communication organization and documentation is done by the IH engineer.

As long as the problem stays line-internal, the process works quiet well due to the short distances. Even the reaction time is short because all required personnel are located at the line. The line IH maintenance worker can start working very quickly after a breakdown (advantage of decentralization). If the WS is required, the communication takes place mainly via phone calls due to the far distances.

Reasons why the WS is needed could be:

- Lack of competences (not all line IH have the same skills)
- IH staff is missing at the line
- Additional man power is necessary (Table 3)

The communication with the WS and especially the process at the WS to process the task is very inefficient. That leads to a bad documentation of the task. What the process at the WS side looks like can be seen in figure 33.

3.2.4.4 Supporting Processes

Beside the main maintenance processes, the autonomous-, the planned, and the unplanned maintenance, some supporting processes for carrying out these main processes are required. These process are very important for the whole maintenance activities and will be explained hereunder.

Spare Part ordering Process:
The spare part ordering is done currently by the maintenance engineer. If a spare part is needed, the engineer has to search for the spare part in an excel list. If the part is available at the storage facility, a maintenance employee has to go to the spare part storage (Bemi)to pick up the spare part. It is a waste of resources, that a well-educated and valuable maintenance employee has to go to the Bemi (Betriebsmittellager, spare part warehouse) storage to get needed spare parts and wastes his time waiting.
If the IH cannot find the right spare part in the excel sheet he has to check if similar parts meet the requirements of the original parts and can be used. For checking if the alternative part can be used, he has to use the internet. Sometimes adaptions on the non-original parts are necessary. If this is necessary, the engineer has to contact the WS and ask if the adaptions can be done by them. If so, a date for delivery has to be negotiated. If the WS is not able to do the adaptions, external companies have to be contacted. The negotiations about the price, the task and the delivery date are sometimes very time-consuming and not standardized. For the standard case, the spare parts needed are available at the storage. Therefore optimizing this process for the future could save a lot of valuable time. The process can be seen in the figure 34 below.

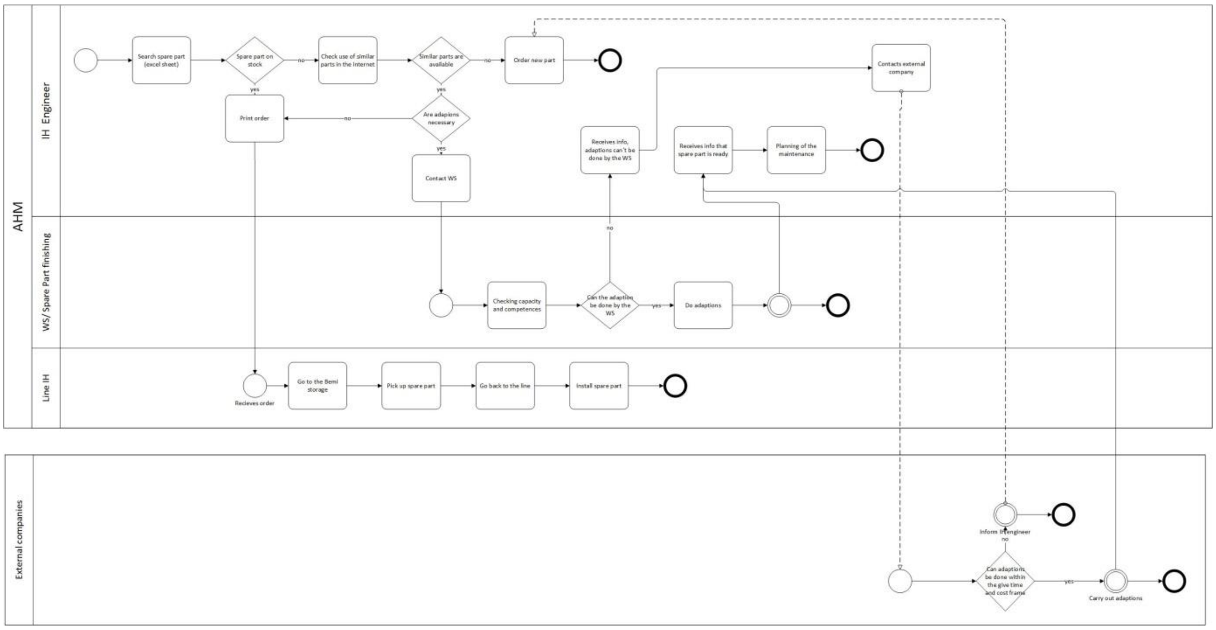

Figure 34: Spare Part ordering process

Ordering WS or external Staff:
Sometimes the resources of human work force at the line are not enough or the skills are missing to accomplish specific maintenance activities. Therefore additional help, either from the WS or from external companies, is required. In such case, support by the WS or external companies is required. For this urgent additional staff demands the process is not standardized. The main communication takes places via telephone or e-mail. Just a very little amount of communication is done via the SAP system.

Task Prioritization:
A prioritization of the tasks is necessary if the centralized plant service is needed and the capacities are not enough to serve all requests at the same time. So called critical lines which are defined by the management have the highest priority and tasks have to be done first. These lines change over the time. Priority 1 means, even if TPM activities are planned or currently executed at a prio2 line, in case of an unplanned maintenance at one of these prio1 lines, the maintenance staff has to fulfill the task at the "prio1" line first. If there are not enough capacities at place, the maintenance staff hast to switch from the line with "prio2" to "prio1" lines even if the work has not been finished yet at "prio2". These procedures might definitely cause problems for lines with planned maintenance activities, which are not carried out due to this prioritization (prio) regulation. In figure 35 the prioritization regulatin can be seen.

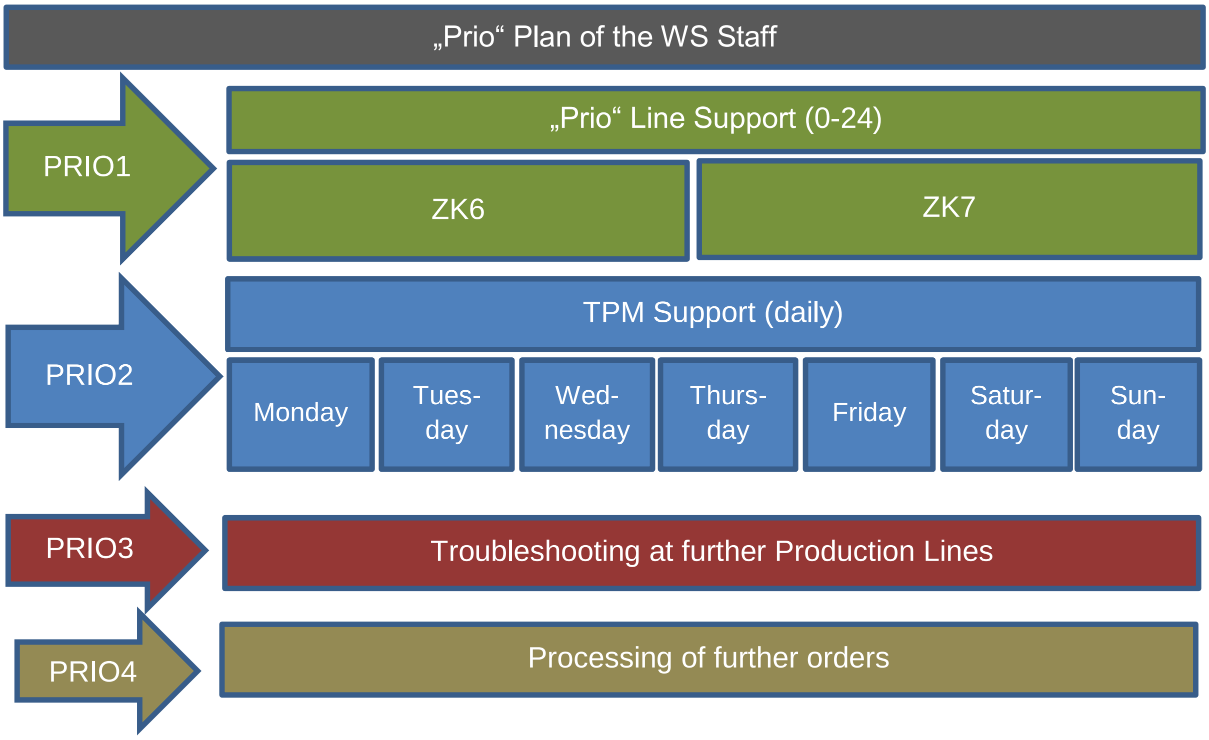

Figure 35: Line and task prioritization, AUDI internal document

3.3 Summary

As explained in the previous chapter the maintenance activities at AHM can be divided up into:

- Autonomous maintenance
- Planned maintenance
- Unplanned maintenance

Optimizing these processes will improve the whole TPM and maintenance activities. The table below (table 9) shows at the x-axis all maintenance activities from autonomous over planned to unplanned maintenance activities and further tasks which have to be accomplished, on the y-axis all people involved. The marks in the matrix show who is responsible for which task.

Organization	Personnel	Activitis													
v: If plant service staff is needed or for company holyday maintenance planning (BU Betriebsurlaub) o: just minor activities		Development of the TPM standard	Executes the in TS02 defined actions	Documentation of autonomous maintenance ativities	Planning an coordination of "planned" TPM activities	Execute planned TPM activities	Documentaion of planned maintenance activities	Coordination of unplanned TPM activities	Execute unplanned maintenance activities	Documentation of unpanned mantenance activities	Responsible for the production and production goals	Finishing Spare Parts	Repair of facility components (Spindle,..)	Responsible for emulsion Supply	Problems wiht engine transport (from the line to the stock)
Production Line	Production Employee		x	x			x			x	x				
	Team Coordinator										x				
	FTL										x				
	IH		x	x		x			x						
	IH Engineer	x			x		x	x		x					
	Head of Production Line	o									x				
G/PT-1 Plant Service	IH					x			x						
	Spare Part Finisher											x			
	Component Repair												x		
	IH Engineer				v			x							
G/PT-3 Spare Part Storage, Engine Handling	Machine Operator														
	IH														x
	IH Engineer														x
G/PT-5 Fluid Management	Process Technician													x	
	Facility Technician													x	
External Staff	External Staff					x		x	x						
	Equipment Manufacturer	o							x						
		Autonomous Maintenance			Planned Maintenance			Unplanned Maintenance							

Table 9: Matrix of maintenance activities and people responsible for them

After analyzing the as-is situation by focusing on the structural organization (centralized, decentralized) and the process organization (autonomous, planned and unplanned maintenance) first statements about the efficiency the flexibility and the uniformity of the processes can be given.

- Enormous production (area, production lines)
- Hybrid maintenance strategy (centralized 20% and decentralized 80% of the maintenance worker)

- Variety of production lines
    - Complexity and types of lines
    - Variety of machine types
    - Complexity of machines
    - Equipment manufacturers
    - Production program (shift model)
- Prioritization of critical lines
- Amount of involved people

Structural Organization:
A main focus in the further work is the used concept of a hybrid strategy of centralized and decentralized organization. Most of the TPM autonomous maintenance activities approximately 95%[27] percent are carried out by the decentralized organization, that means that the production lines with their machine operators and maintenance staff do that work. The remaining 5% of the autonomous maintenance amount is done by the plant service and external companies.
One point which will influence the flexibility of the organization is finding the right ratio of outsourcing. Most of all maintenance activities concerning robotics are done by external companies. Just simple activities are carried out by the in-house maintenance staff. There are trainings held by robot manufacturers but the learning effect and success is very different from person to person. The question arises: should more competences be developed in house or should the robotic maintenance largely remain outsourced. Concerning the flexibility and the independence, a special in-house robotic maintenance team would bring advantages. However, a strong argument against bringing robotic competences in house is the huge variety of manufactures and types. Therefore it has to be calculated if a centralized, decentralized or manufacturing type organization is preferred.
One big problem that affects the structural organization is the fact, that not enough well-educated and qualified personnel for maintenance can be recruited. As mentioned in this thesis, within the whole AHM more than 30 maintenance employees are missing. One reason simply is that they are not available on the market. This fact has also to be taken into account when developing a new organization. Due to this fact, modern technologies for reducing the amount of human personnel on-site can be used, for example a video transmission done by the machine operator in case of an equipment failure to the IH engineer for example. Therefore the IH engineer, regardless of where he works at the moment can see what is happening there and make suggestions for repair.

Process Organization:
The process organization in contrary to the structural organization, is not so clear. There are many processes which are not executed in an identical way between the different lines. Not all lines use the same TPM sheets (TPM sheet matrix). There are defined processes for three main functions:

- Autonomous maintenance
- Planned maintenance

[27] Information are from an AUDI internal presentation

- Unplanned maintenance

What these processes look like has already been mentioned in this thesis. What they look like in detail is different from line to line.
Weak points of the current process organization:

- Low digitalization (TPM sheets in paper form, except Win TPM)
- Little automatization in the processes (no system with predefined workflows)
- Little or poor documentation, know-how not centrally accessible
- Poor communication between the segments
- Communication to the centralized organization (WS) is poor
- No standardization, lines work in different ways

4 Requirements for a new TPM-Organization

Now after analyzing the as-is state, some weaknesses of the current organization become evident. By keeping the potentials for improvement in mind, new targets and requirements have to be defined. Which properties a new organizational structure has to have in order to guarantee a flexible and efficient maintenance will be shown on the next pages. With explicit consideration of what the future challenges (Maintenance 4.0[28]) of maintenance will be and to be prepared for these changes, some requirements are stated. At first some general requirements followed by conceptual and specific requirements for the new concept will be listed.

4.1 Increase OEE

As already mentioned, the OEE value is the most important indicator for the production efficiency and therefore to increase this value is always an objective. How this value is calculated at AHM will be explained in the next chapter. Figure 36 visualizes indicators which are important for an appropriate OEE calculation.

[28] Kagermann H., Lukas W. D., Wahlster W., Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. Industriellen Revolution, VDI Nachrichten, April 2011

Calculation of the OEE at AHM[29]:

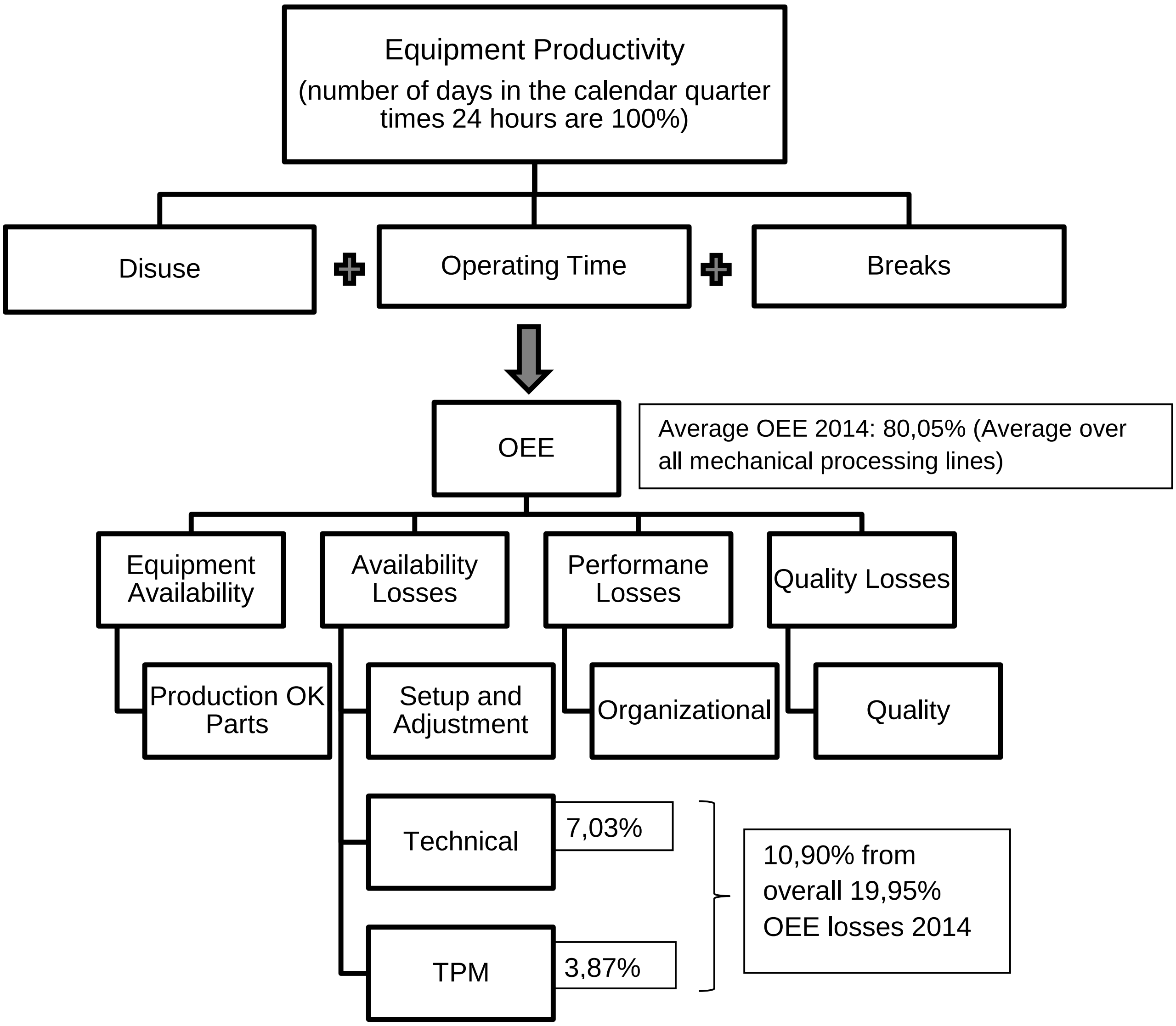

Figure 36: OEE calculation at AHM; modified from Audi internal document

Operating Time[30]: Time where the production line is basically available for production. Therefore the real shift times are taken. Stoppages caused through TPM or planned repair are included.

Technical (unplanned events):

- Unexpected failure/ downtime
- Unplanned tool change
- Downtime due to unplanned maintenance
- Start-up of machines

TPM (planned events):

[29] Numbers for the calculation are found in the Attachment
[30] Information from AUDI internal documents

- All TPM activities carried out by internal or external staff
- Planned inspection/ Service or Cleaning
- Planned Repair

Derived from this information, the highest potential for increasing the OEE is to reduce unplanned maintenance actions and to optimize planned maintenance activities (TPM activities). In other words, to decrease unplanned maintenance (technical) losses.

4.2 Reduction of overall Maintenance Costs

Cost reduction is always a goal. It is important to consider, that the overall cost (downtime costs, production loss) are decreased, not just the maintenance costs. The challenge is to find an optimal solution. Therefore the OEE value has to be included in the deliberations as well as effects on flexibility. Aspects, such as expenses for external- and internal maintenance also have to be under investigation to define the overall costs.
How organizational changes influence the degree of flexibility, has to be considered at all times. To increase the OEE value and the flexibility by simultaneously decreasing the maintenance cost would be the best-case scenario.

Parameters which have to be considered are:

- Personnel costs
- OEE
- Costs for infrastructural changes
- Flexibility
- Internal maintenance costs
- External maintenance costs

4.3 Flexibility

In the relevant literature, there is no definition of flexibility that is universally accepted. Along with the difficulty of a conceptual unification of the term, there is also the great variability in the fields of application of the concept of flexibility (Toni & Tonchia, 2005). From a overall point of view, flexibility is defined in various ways.
The definitions of flexibility which are found in literature either are derived from a general definition which originates in other fields and applicable also in other contexts or originate directly from the managerial field depending on (Alberto De Toni, 2005):

• an economic approach,
• an organizational approach,
• an operational approach,
• a strategic approach.

On the following pages, some basic definitions of the term *flexibility* will be listed. The focus will be on organizational flexibility: the general understanding of flexibility in the organizational context, which dimensions a flexible organization has and which are of special interest for the organization at AHM.

General Definitions of “Flexibility”:

- “*Ability to respond effectively to changing circumstance*s.” (Gerwin, 1987)
- *“The adaptability of a system to a wide range of possible environments that it may encounter*” (Sethi, 1990)
- *“The ability of the system to quickly adjust to any change in relevant factors like product, process, loads, and machine failure”* (Nagarur, 1992)
- *“A generic ability to adapt to internal and/or external influences”* (Holweg, 2005)
- *“The capability of an organization to move from one task to another quickly and as a routine procedure”* (Vokurka, 1998)

Organizational Flexibility:

The organizational approach deals with models of organization that enable a firm to operate responsively in a rapidly changing environment, including labor flexibility as an individual (Atkinson, 1985) or team (Meyer, 1994) ability. “*To obtain flexibility, the nature of the firm’s organization is essential as are the attitudes of people towards change and assumption of the risk”* (Carlsson, 1989). At the macro-organizational level, the contributions of Burns and Stalker (1961), with the concept of the “*organic*” (as opposed to the “*mechanistic*”) structure and Mintzberg (1979), with the concept of “*adhocracy*” are of particular importance. Jennings and Seaman (1994) demonstrate that organizations with a high-level of adaptation have an organic structure (instead of a mechanistic one) and adopt a prospector strategy (instead of a defender strategy). At the micro organizational level, this theme is correlated with the job enrichment/ enlargement concepts and compensation/incentive practices (Nemetz & Fry, 1988). Upton (1995) argues that the “*flexibility of the plants depends much more on people than on any technical factor equipment and computer integration*”. Suarez et al. (1995) maintain that “*flexibility has much more to do with non-technology factors than with technology itself*”. Schonberger (1986), with the term “*frugal automation*”, intended to stress that flexibility was not so much the ability to produce a high number of different codes as the ability to pass from an efficient type of production to another equally efficient one by making organizational-managerial choices which require lower investments in terms of fixed assets (thus the definition “*frugal automation*”). Furthermore, there are also studies which take into account the influence of the country-system where the firm operates, culture, education and training, relations with trade-unions, etc. (Gerwin & Tarondeau, 1989). (De Toni & Tonchia, 2005)

Dimensions of flexibility according to (Goldena & Powell, 2000):

Temporal

Temporal flexibility, can be described in terms of the duration that it takes an organization to react to environmental changes. Eppink (1978), studying strategic flexibility, argues that there exists a typology of environmental change: operational, competitive, strategic. He suggests that this typology can be mapped onto flexibility to conceive three types: operational, competitive and strategic. Gustavsson (1984), studying flexibility in manufacturing, argues that “*it is essential to identify the critical time perspective or perspectives”*. Gustavsson (1984) divides temporal flexibility into three categories, operational, tactical and strategic. These categories can be divided in short-term, medium-term and long-term actions.

Operational problems (short-term):	>replanning due to breakdown of a machine >unexpected shortage of a raw material.
Tactical problems (medium-term):	>changes in design

>rate of production.
Strategic problems (long-term): >investments in machinery or business expansion.

Range
The degree to which an organization can adapt to foreseeable and unforeseeable changes is the second dimension of flexibility (Eppink, 1978). Eppink proposes that *"…flexibility is a strategic response to the unforeseen"*. Krijnen (1979) provides a definition, which incorporates both foreseen and unforeseen environmental changes. Krijnen (1979) argues that a flexible firm has to have the ability to adapt to stay competitive and ensure continuous improvement. To do so and to achieve the goals there are two possibilities: First, by planning for developments in the environment which may occur (foreseeable events). Second, adapting to circumstances. That means, that events taking place in the environment, which were by no means predictable or foreseeable.

Intention
Intention acknowledges that, companies or organizations are not helpless while changes in the environment have to be done. This dimension of flexibility is the degree to which organizations take an offensive or defensive stance towards flexibility (Avison, et al., 1995) (Evans, 1991) (Gerwin, 1993). Organizations which take an offensive role can gain competitive advantage because they try to control change in the environment, while defensive organizations just react to changes after they have already occurred. Minimize the impacts is the main focus using a defensive strategy. This attempt to flexibility has also been described as active or passive (Eppink) (Volberda, 1998).

Focus
Flexibility mainly is created in the last dimension of flexibility which is focus. Ansoff (1965) suggests two types of flexibility, internal and external. In doing so he provides the earliest reference to this dimension of flexibility. Das and Elango (1995) adopt this dimension of flexibility and provide a list of areas where both these dimensions can be obtained. Important areas or departments where internal flexibility can be created are: manufacturing (production), employee flexibility and organizational structure. External flexibility mainly is created by suppliers, alliances, and multinational operations.

Metrics of flexibility according to (Goldena & Powell, 2000):

Efficiency
In manufacturing, Anderson (1993) defines flexibility as "*the ability of the production system to accommodate change with minimal degradation of performance*". Upton (1994) describes efficiency as "*the ability to maintain uniformity of some performance measure, such as yield or quality, within a range of possible production*". Thus, in manufacturing, one metric of flexibility is the ability to maintain efficiency while accommodating or adapting to change.

Responsiveness/ Reactivity
To react on changes within an adequate time frame is essential and an important metric of flexibility. Eppink (1978), proposes that *"…one of two options which an organization has, is to increase its response capacity to unforeseen environmental change"*. Bolwijn and Kumpe (1990) believe that to respond is the ability to change quickly in response to change. Evans (1991) calls this responsiveness "*an expedient capability"* to deal effectively with changing situations.

Versatility

Responsiveness measures speed while versatility measures the extent to which the organization has planned for, and can respond to, environmental change. Moreover, versatility is a measure of the range of activities that the organization has contingently planned for. These plans are formulated on the basis of changes that could be foreseen. Krijnen (1979) argues that strategic flexibility possesses elements which prepare for the foreseen and provide avenues to react to the unforeseen.

Robustness

To react effective on unforeseen environmental changes is what robustness represents (Eppink, 1978). This metric of flexibility can be compared with versatility, the ability to respond to foreseen events (Krijnen, 1979). The nature of the unforeseen changes are defined by Aaker and Mascarenhas (1984) as substantial, fast-occurring changes which take place in an uncertain environment.

Figure 37. Relationship of metrics of flexibility to the dimensions of flexibility. The four metrics of flexibility are outlined; efficiency, responsiveness, versatility and robustness. Specifically, efficiency and responsiveness measure the temporal dimension while versatility and robustness measure the range dimension. Efficiency measures the degree to which organizations meet the challenge within the time constraints imposed, and responsiveness measures the time it takes to adapt to new circumstances. Versatility relates to the capability of the organization to respond to situations which it has foreseen and robustness is the ability to adapt and respond to changes which it did not foresee.

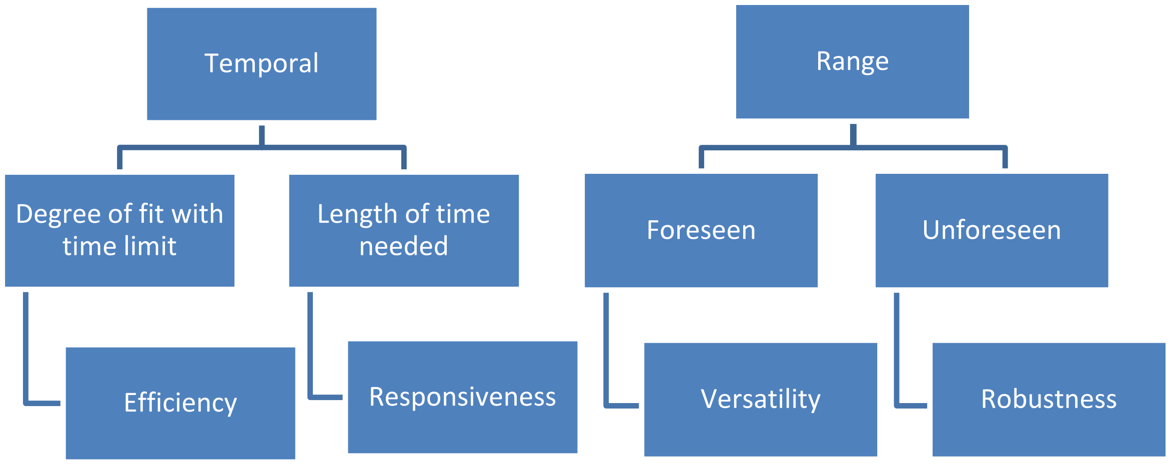

Figure 37: Link between dimensions and metrics of flexibility; Goldena & Powell (2000)

Summary:

For the maintenance organization at AHM, in particular the TPM activities, flexibility is a factor which has to be considered. In this context flexibility has three main dimensions (time, focus and range).

Time or temporal factors in specific on the short term base: how fast the organization can react to new events, how flexible the organization is if unplanned work beside the routine activities have to be accomplished. Time in all business processes is always a critical success factor. Therefore, a fast adapting organization to new situations is necessary for staying competitive. For AHM the main focus is on temporal flexibility.

Focus is a very critical topic and also requires some strategic planning. According to Ansoff (1965) focus can be distinguished between an internal and external focus. For the maintenance at AUDI that means a big challenge. The production equipment is getting more and more high-technologic, even the range of different assets is growing rapidly. Also high-tech equipment is needed for the repair of production equipment. Now the important question is, which repair is performed in-house and is considered a core competence of AHM and which service tasks are better outsourced because of a lack of competence. For outsourced maintenance activities the contract negotiation with the involved companies is a very important task for ensuring a fast and unbureaucratic service. Which tasks should be outsourced and which should be done in-house is a topic for further investigations as handling it within this thesis would be too extensive.

As to **range,** it is particularly important how to react to foreseen and unforeseen actions. For AHM that means planned versus unplanned maintenance activities: how flexible and how fast the system can adapt to new circumstances and conditions.

The dimensions relevant for AHM are shown in figure 38 below.

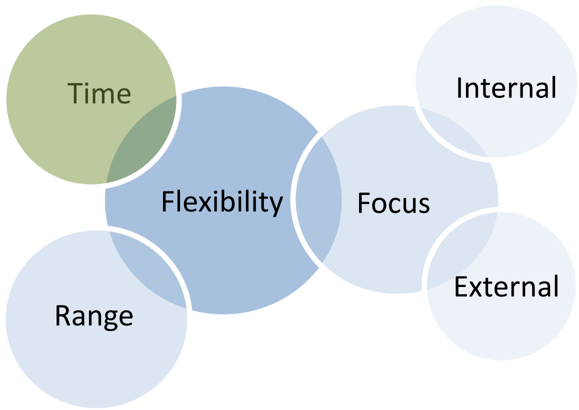

Figure 38: Dimensions of flexibility in connection with maintenance at AHM, modified from Goldena and Powell (2000)

IT and Flexibility:

Investigations of which influence IT can have on organizational flexibility are done since just a few years. Suarez et al. (1995) argue that "*Information Systems affect flexibility but they subsequently exclude it*". (Goldena & Powell, 2000)

Positive Impact of IT on Flexibility

Lucas and Olson (1994) state that IT contributes to organizational flexibility in three ways:

I. By changing the nature of organizational boundaries and the time when work occurs.
II. By altering the nature and pace of work.
III. By helping firms respond to changing market conditions.

Continuous improvement processes will be influenced in a positive way by using information technologies. A fast information distribution is mainly supported by, central documentation and knowledge management tools. The share of information enables an adaption of best practice actions. Not just in the affected organization or department even in other areas which are not directly linked. (Goldena & Powell, 2000)

4.4 Conceptual Requirements

The overall goal, which is always aimed at in production and maintenance, is increasing the OEE value to a maximum. To realize robust, interruption-free production and to react fast and reliably in case of breakdowns, three basic areas were under investigation:

I. Introducing the right maintenance strategy
II. Finding the right organization (organizational mix)
III. Improving processes (maintenance system)

Finding the right strategy which meets the requirements of the company best is a true challenge. Thereby it is important to implement a strategy which improves the production, maintenance and the OEE while at the same time monitoring the cost effect. Finding a strategy with the best effort/- profit ratio is essential.
The organizational structure has a main influence on flexibility and also directly affects the OEE which influences the overall production costs.
In order to improve the processes and to enhance continuous improvement processes a new "intelligent" maintenance system which contains all required functions, basic TPM activities, spare part ordering, documentation, communication and trainings has to be introduced. All required information, processes and actions have to be treated within one, easy to use system.
Maintenance 4.0 deals with the comprehensive digitalization, supervision and analysis of the entire production equipment. Linked cyber-physical production systems support condition based and predictive maintenance.
How important the implementation of maintenance software is can be seen in figure 39 below. A survey done for the report "Roadmap der Instandhaltung 4.0" (Güntner, et al., 2015) shows how many of the companies questioned already have maintenance software in use, how many plan an implementation within the next five years and for how many firms implementing such a software is not an issue at all.

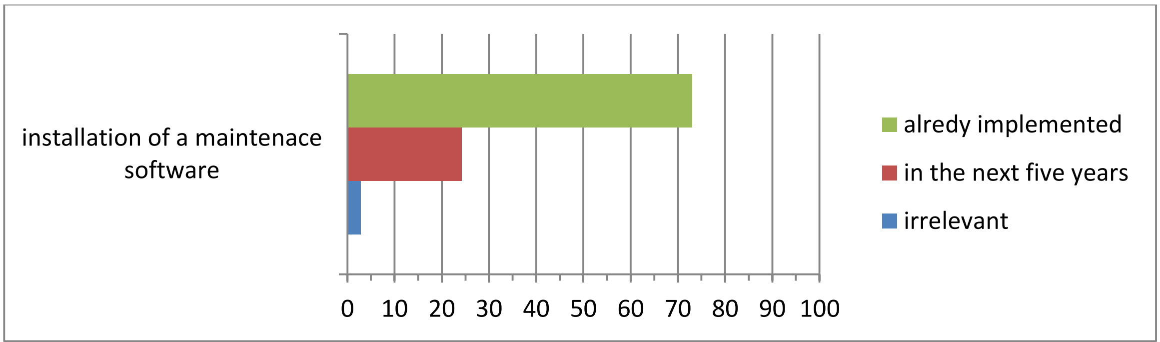

Figure 39: Companies and their position to maintenance software implementation; modified from Güntner et al (2015)

In figure 40. the general trend for the visualization of information and maintenance tasks is shown. Thus, 30% of all companies interviewed already use mobile devices like tablets and smartphones for the visualization of relevant information. Furthermore, over 60% plan the implementation of mobile devices in maintenance activities within the next five years. Just a minority of less than 10 % are not thinking about this issue.

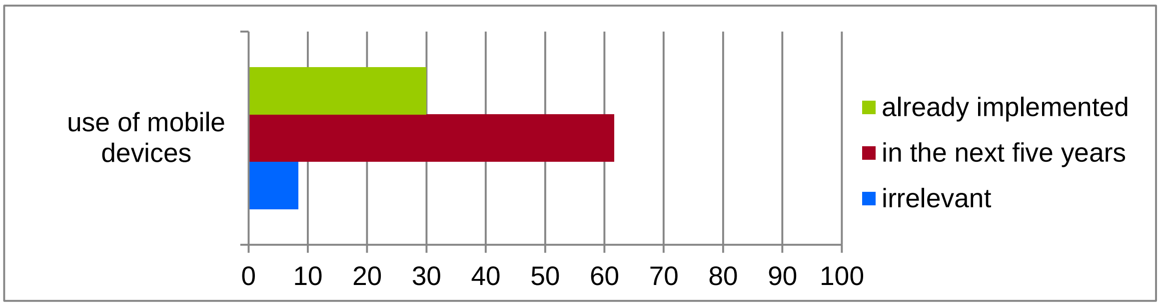

Figure 40: Trend for information visualization; modified from Güntner et al (2015)

Smart Maintenance is the future, but the implementation of such a holistic Maintenance system with an up to date visualization technology (tablet, smart phone) brings about a lot of facts which have to be considered:

- Establishment of new work practices and processes
- Choosing an appropriate maintenance strategy
- Data analysis
- Deviation of helpful actions from the analyzed data
- Acceptance of the people involved
- IT expertise
- Continuous improvement

4.4.1 Maintenance Strategy

The way the organization should look like in particular is mainly affected by the implemented maintenance strategy. The staffing has to be done totally different if a reactive maintenance or a preventive strategy is chosen. For a crash strategy for example a lot of maintenance staff for all possible breakdown reasons has to be in-house around the clock. If planned maintenance with condition monitoring or similar practices are in use, ad-hoc maintenance will decrease. For this reason, even the amount of “emergency” maintenance staff can be kept at a minimum. One strategy which meets all requirements for the future and furthermore perfectly fits to the Audi philosophy and current maintenance organization is predictive maintenance in cooperation with the already implemented TPM strategy. With the already collected data from BDE there is a good base for implementing such a strategy. The fact that the maintenance tasks can be planned, reduces the need for a flexible organization considerably. If future actions are known beforehand it is not necessary that the organization has to “react” to unplanned events.

Predictive Maintenance:
For implementing predictive maintenance, information about the production equipment is essential. This information could be provided by the already existing BDE system. Noise- or vibration analysis can be done in addition. Analyzing the collected data therefore provides useful and adequate information for the people involved. Figure 41 shows the process which has to be carried out in order to successfully implement a predictive maintenance strategy. This process was developed in cooperation with AHM. The data acquisition and the collection of this data is the first step. Derived from the analyzed data information about equipment conditions can be provided. Such provided information is the basis for planning maintenance actions to avoid unplanned maintenance activities.

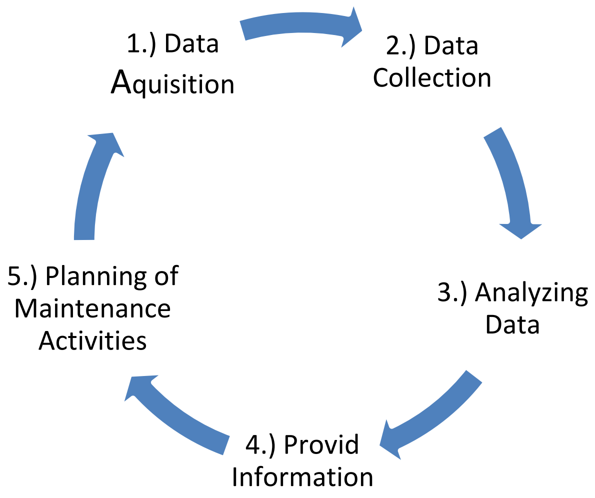

Figure 41: Cycle for predictive maintenance, developed in cooperation with AHM

The investigations have shown, that the highest need of system flexibility belongs to unplanned maintenance activities. That means that, if a predictive maintenance system can be implemented successfully, the number of unplanned maintenance or repair activities will decrease. This decrease of unplanned maintenance activities will have a positive influence on the needed structural flexibility.

4.4.2 Structural Organization

The investigation of the as-is state has shown, that the organizational structure with the centralized and decentralized components for AHM is the most efficient one. Especially the satisfaction with the organizational structure of the production lines is quite high. The capacity of the plant service (WS) is one point of criticism. Many requests cannot be carried out by the plant service because there is not enough man power available. These tasks then have to be delayed if possible or carried out by external companies. One possibility for increasing flexibility is to increase the amount of man power belonging to the WS. Another possibility for increasing flexibility would be to disburden the WS staff, for example by adapting the number of maintenance staff at lines where staff is missing.

Implementing a totally different structural organization was under investigation as well. The focus was on flexibility but also on costs. Some options for a structural reorganization which have been investigated will be explained.

1. Complete Centralization

The overall number of maintenance workers from the centralized and the decentralized maintenance organization currently exceeds 160. The planned number of IH workers is 197 but some decentralized maintenance positions are not occupied. The planning effort for so many people is enormous. A centralized organization can perform efficiently just if the share of planned maintenance activities is high. If many unplanned maintenance activities occur, this organizational form is not the right one.

Beyond this fact, the infrastructure for so many centralized maintenance people is not given at AHM. To adapt the WS for this strategy a lot of reconstruction work which will cause immense costs would be necessary.

Disadvantages:

- High planning effort necessary (for 2014 approximately 3950 ad-hoc requests at the decentralized organization for 33 WS employees)
- No sufficient infrastructure available
- Not appropriate for a high amount of unplanned maintenance activities
- Long distances between the lines
- Huge asset variety (specific know how needed)

Advantages:

- Good cost overview

2. Complete Decentralization

A total decentralization will have a negative influence on the flexibility compared to a hybrid strategy. It leads to flexibility which is entirely dependent on external service providers (critical in reaction time and costs).

Disadvantages:

- Flexibility causes high fix costs
- Flexibility only through external companies

Advantages:

- Focus just on a few machines
- Short ways
- Specific know how
- Fast reaction in case of unplanned maintenance activities
- People feel responsible for the line

4. Maintenance Teams for Production Segments and Centralized Organization

The total number of IH has to stay the same, independently from whether the maintenance workers are assigned to one specific line or to the whole segment. The incoming work has to be done and therefore this amount of IH people is seeded to do so.

Disadvantages:

- Far distances between the lines
- Know-how for each line type is needed
- Additional organizational unit is needed (line IH engineer per line is not enough, someone has to do the coordination for the whole segment)

5. **Machine Type Maintenance Teams and Centralized Organization**

The fact that production equipment from 54 different manufactures is in use and that the machine age varies from brand new to more than 20 year old machines makes it obvious that dividing the maintenance to machine types is critical and will not improve the maintenance performance.

Disadvantages:

- Huge variety of machine types
- Huge number of equipment manufacturers
- Huge variety in the machine age
- Far distances between the different lines

4.4.2.1 Plant Service

Currently the capacities of the plant service (WS) are very restricted. Therefore many requests for maintenance support from the lines have to be rejected. If the activities are urgent, and in most of the cases they are urgent, the tasks have to be outsourced to external companies or delayed if possible. Generally, external repairs are more expenses than in-house repair activities. Finding the right amount of in house maintenance staff is a big challenge and a main cost factor.
Also the spare part finishing department has potential for improvement, but this fact is not investigated in this thesis, because it will go beyond its scope. Many spare parts cannot be finished in-house. Reasons therefore are:

- Lack of personal to process all orders
- Lack of competences to fulfill the task
- Lack of equipment to accomplish different tasks

4.4.2.2 Organization Production Line

The basic organization at the production line is efficient and works well if all intended positions are occupied. The fact that so many maintenance people over all lines are missing has an influence on the entire system. The plant service is not designed for so many support cases caused by the missing line IH staff. This fact influences the OEE in a negative way and also has a negative influence on the overall production costs. Due to the fact that the incoming work exceeds the capacity of the WS, many tasks have to be outsourced to external companies. The costs for external maintenance has to be reduced and can be reduced simply by adapting the number of line IH to the target.

4.4.3 Maintenance System

For boosting TPM and the maintenance activities in general to the next level, the implementation of a computer supported maintenance system is essential.
As already mentioned in the introduction of this chapter, a specialized maintenance software fitted to the specific requirements is essential. For a cost efficient and easy-to-adapt solution it is crucial to employ software packages which are currently in use.
Currently three software tools exist with a high potential for supporting a new maintenance software and predictive maintenance philosophy are existing. The already existing tolls are shown in figure 42.

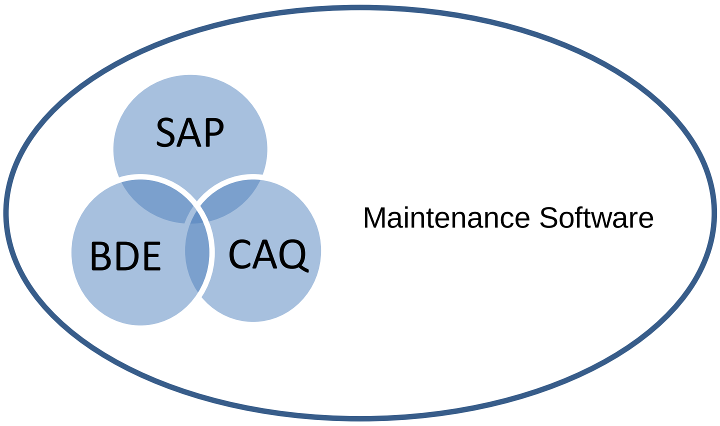

Figure 42: Existing software tools at AHM

SAP:
The SAP system is widely used for different business processes within AHM. It is mainly used for spare part tracking and ordering. Even all production lines and the asset are indicated very well within this system. The staff accounting is also done using SAP. One negative point is the fact, that the system is not very user-friendly. For non-specialists it is complicated and not really intuitively useable. A positive argument for SAP is the wide range of different stored data in the system. So, for a new simply to use maintenance system, SAP is a very good source of information and can be used as a database.

BDE/ PDA: (Betriebsdatenerfassung/ Product data acquisition)
Nearly all of the mechanical processing lines are equipped with this system, which offers information in different categories to a different extent to different groups of employees.

Information categories

- Error message
- Procedural message (Betriebsmeldung)
- “Unimportant” message (not further specified)

Information separated to employee groups:

- Administrator
- Head of the production line
- Maintenance engineer
- Machine operator

The acceptance and the trust in this system, in particular, by the elder generation of employees is low and thus poses a problem. To strengthen the acceptance and to provide user-friendly information is a challenge for the future.

BDE Data analyzing:

A future possibility and a target is to analyze all collected data from the BDE system to derive machine conditions from this information, which is very important for predictive maintenance condition monitoring of the production equipment. Condition monitoring brings an advantage in planning of maintenance activities and additional flexibility. At the moment it is hard to predict which information is needed to derive equipment conditions. How reliable this information is can only be anticipated now. The real validity of the value of the information will become clearer over time. So, at the moment the TPM organization can just pay limited attention to this future project.

CAQ:

All lines from the hardware side are equipped with this system. Some assembly lines already use this system for supervising the production. The system consists of the following main parts:

- Product related
  - Product tracing
  - Reclamation
  - Inventory tracing

- Asset related
  - Condition
  - Tool management
  - Maintenance
- Process related
  - Work order
  - Conveyer logistic
  - Andon board visualization [31]

The product-related and the process related parts are already in use at some assembly lines. All asset-related tasks are not in use at the moment but especially for maintenance stuff such a system would improve the performance.

Conclusion:

For an efficient TPM organization a system similar to Computerized Maintenance Management System (CMMS), which are already available at the market, is essential to have. Therefore it is inevitable that the currently existing systems are interconnected. A smart system needs information from all sources and provides information to several processes and to everybody involved.

[31] Developed by Toyota (TPS). A „Andon board“ is a digital board which provides production information to the employees

What is CMMS?

"A CMMS system can help departments become more efficient in: tracking maintenance procedures; maintaining data on equipment, schedules, and downtime; providing one point of interaction with operational applications, processes, and people; maximizing limited resources; optimizing performance and maintenance schedules to maximize equipment uptime; and controlling costs by using existing resources more efficiently." (Santangelo, 2015)

4.5 Specific Requirements

Besides the general requirements the new organization has to meet some specific needs which have to be defined. These changes are essential for a future-proof proactive maintenance. As already mentioned in chapter 3.3 a digitalization of all TPM activities and processes is mandatory. The basic idea is a software solution combining all processes linked to maintenance. It is important that the new system is as easy and as user-friendly as possible. For standardizing the TPM procedure, it is crucial to make processes comparable and documentation easy to produce.

4.5.1 Digitalization of the TPM and Maintenance Sheets

The number of TPM sheets is enormous. All these sheets are stored in paper form and thus extremely outdated for evaluations and analyses. Especially when specific information is needed, it is a lot of work to find the right one. For the machine operator the whole procedure is very time-consuming, especially if he is not so experienced. He always has to keep in mind which task has to be done. Furthermore, he has to search the information needed (service methods, settings, etc.) in the TPM sheets. And finally he has to confirm the fulfilled task on another sheet. Making this process easier and more efficient is mandatory. If the autonomous maintenance can be done faster and easier, the machine operator has more time to look after the production, which is his actual main task. In order to simplify the TPM activities a system similar to the existing WinTPM system, definitely with some improvements is needed in the future. If the visualization in the future will be done not only on the touch panels at the machine terminals, mobile devices like smart phones or tablets will take over this part.

Advantages for the machine operator:

- automated notification when the task has to be fulfilled
- tasks will not be forgotten
- information is directly linked to the task
- no searching for the service methods or setting and operating data in the sheets is needed
- documentation is easier

4.5.2 Improve Plant Service ordering Procedure

The process for ordering the WS or external staff at the moment is no entirely standardized, not efficient and time consuming. Within the new maintenance software an automatized workflow for this event has to be set up. All demands for the WS have to be processed in one system which is connected to the available staff. A prioritization of the tasks in accordance to the production program of each line is done: the information about when and by whom the task will be accomplished is delivered automatically to the person who has sent the request.
A similar process for recruiting external staff is needed too. These companies probably have no access to the internal system, therefore an automated e-mail delivery can do the task. The IH engineer has an input mask where he can fill in all the requirements (date of repair, which task with description, etc.) and send this information directly to the company he wants to hire workers from.
The company will check the request and send back information to AHM.

4.5.3 Improve Spare Part ordering Procedure

The spare part ordering process has high potential for improvements. At the moment the process in terms of efficient resource utilization is poor.
First, the maintenance engineer has just Microsoft Excel documents to his disposal for searching the needed spare parts. This time-consuming process can be optimized by the implementation of a database which makes the query for specific parts easier.
The role of the maintenance staff in connection with ordering spare parts has to be considered as well. Currently well-educated employees have to pick up the spare parts at the spare part storage (Bemi). Considering the huge production area, the distances from lines to the Bemi storage can be very long. There are also often waiting times at the issue desk. All these facts together are very time-consuming and have to be optimized.
This fact has to be considered in the structural organization. One possibility would be a delivery Service, by the spare part storage. This process should work similar to online orders. The maintenance engineer sends the needed information about the spare part to the spare part storage. The spare part storage receives the order and delivers the desired part to the desired place at the desired time.

4.5.4 Visualization

One very important issue with high potential is the visualization of all the maintenance activities and actions. Generally the information technology and even the end-user devices are changing. The noticed trend, as already mentioned at the beginning of this chapter are mobile devices such as tablets or smart phones. To use such technologies has many advantages.

- People are not bound to one place
- Information is available everywhere by internet or intranet
- Information can be shared instantly
- It guarantees efficient processes

As the use of smart phones makes our lives easier, mobile devices in maintenance would make work easier and more efficient as well. All the information is passed on directly to the

employee at the place where it is needed. One argument to be considered could be that the people have to know how to use these technologies properly to add value to their daily work. There are two points to prevent the people from stress by using the new technologies and improving their maintenance performance.
The system and the use have to be as easy as possible. Trainings on how to use the mobile devices properly and, which possibilities these devices offer eventually are important points. These training units should improve the overall performance and simplify the employees´ work.

4.5.5 Summary

All these requirements described have to be considered as implementations in the new organization structure in order to stay competitive. The requirements besides an adequate strategy can be introduced to the structural organization and the process organization.
Flexibility affects the structural organization: the number of people included in maintaining activities, the skills of the people and which tasks they can perform is a dimension of flexibility too, and last but not east the ability of the organizational structure to react on new and unplanned events. All these facts have to be supported by uniform processes. A major point of discussion concerning flexibility in the maintenance organization is the question of core competences in-house and outsourcing activities. To find the right mix of both strategies is a significant strategic decision and cannot be finally answered within this master thesis. The implementation of maintenance software will definitely support the organizational flexibility.
As already mentioned, the used maintenance strategy has influence on the organizational structure too. TPM as the chosen strategy requires a different staffing compared to a reactive maintenance strategy for example. The TPM actions in the future should be supported by condition-based or predictive maintenance. Deriving equipment conditions from the already collected machine data is a challenge and essential for improving maintenance activities. Currently information about which condition can be predicted with which probability is not available.
All improvements concerning the improvement of the process organization will be generated by the implementation of a software system for maintenance. This system will include several different modules for various tasks. An explicit description and explanation of the system will be given in the next chapter. The main idea behind such a holistic system is that the process will automatically be standardized and reproducible. It will disburden the maintenance engineer at the line who plays the main role in the whole TPM procedures: to provide the possibility to carry out all actions within one single system- from the development of the TPM standard sheet and planning TPM shift to spare part ordering and further actions. Such a system should also enables an easy communication between production lines, the WS and external companies. To standardize communication is a critical success factor for the future.

5 Concept of a new TPM-Organization

A functional maintenance is a key success factor for each manufacturing industry. The increasing need for more flexibility in the production to satisfy customer requirements is rising. Therefore, even the maintenance strategy and organization have to be optimized. Therefore a main focus is on the implementation of maintenance software, which provides a higher flexibility and a more efficient maintenance in general. It supports a better use of the available resources and enables faster and more precise decision making. For the desired maintenance strategy in the future, the collected data play a key role. All defined requirements from the previous chapter will now be proven in the concept.
As shown in figure 43 a lot of data has already been collected. The difficulty lies in obtaining the right information out of this data. If equipment conditions can be derived from the machine data it would lift maintenance to another level. For the future the system should act autonomously and be able to make its own decisions based on the engine data and information stored in a database.

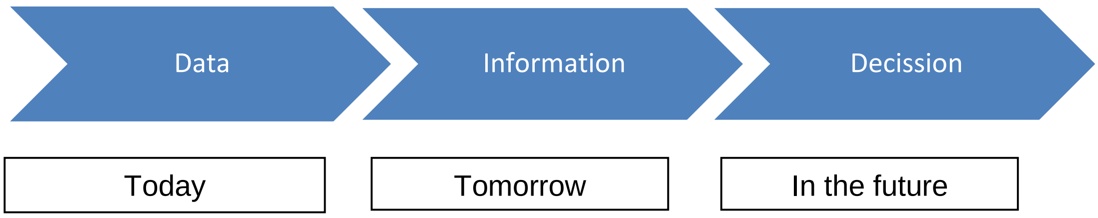

Figure 43: Data and decision making, developed in cooperation with AHM

The concept is divided into three main parts:

I. The maintenance strategy which should be chosen for the future.
II. How the structural organization should be, will be described.
III. The process organization and important new processes will be explained.

5.1 Maintenance Strategy

As already mentioned the desired future maintenance strategy should be a cooperation between a predictive and a TPM maintenance strategy. To verify this statement some facts will be shown.

Planned vs. Unplanned Maintenance:
The main target of a predictive maintenance strategy is to minimize unplanned maintenance activities. To act in most of the cases is cheaper and more efficient than to react to events that have already happened.
Generally speaking, unplanned maintenance is carried out after a machine has already broken down. That means that in most of the cases the production is interrupted (if no redundant machine is available) or the output is reduced (if redundant machines are available). The machine downtime for unplanned maintenance is much higher than for planned repair activities. Not just the machine downtime is higher, even the whole repair action takes longer in unplanned maintenance cases. The two processes will be shown in figure 44 below.

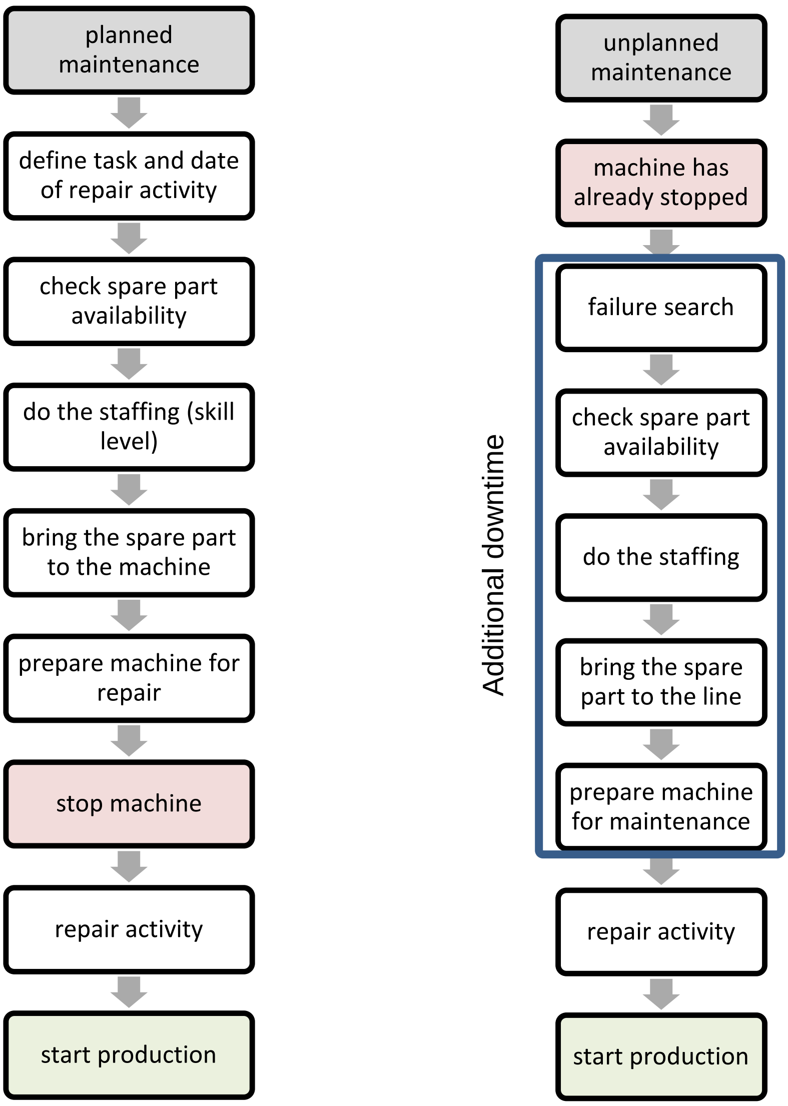

Figure 44: Process of planned vs. unplanned maintenance

As shown in figure 44. it is obvious why unplanned activities are more critical than planned repair activities. In planned maintenance cases many tasks can be done in advance and so the downtime is short. All these tasks and the additional failure search in case of unplanned repair activities have to be done after the machine has already stopped working. That causes long machine downtimes and a loss of production. Critical in unplanned repair cases is the spare part and the staff availability. If the right spare part is not available or if the spare part has to be manufactured it can cause additional downtime. If no skilled staff is available it can cause a delay too. Failure search is a task which only occurs in unplanned maintenance cases and is an uncertainty factor as well.

In table 10, the duration for planned maintenance compared to unplanned maintenance is shown.

Planned maintenance		Unplanned maintenance
Maintenance time	<<	Maintenance time
Downtime	<<	Downtime

Table 10: maintenance time and downtime for planned and unplanned maintenance

The need of a predictive maintenance system is shown by investigating the OEE losses (technical and TPM), analyzing the performed plant service hours calculating the costs of production loss.

5.1.1 OEE Loss Analysis

The following figure (figure 45) shows the sum of all OEE losses in hours caused by TPM or technical losses for 2014. The outcome of this investigation is, that the amount of technical losses is two times as high as the losses caused by TPM activities. This is a further big reason for implementing a predictive maintenance system.

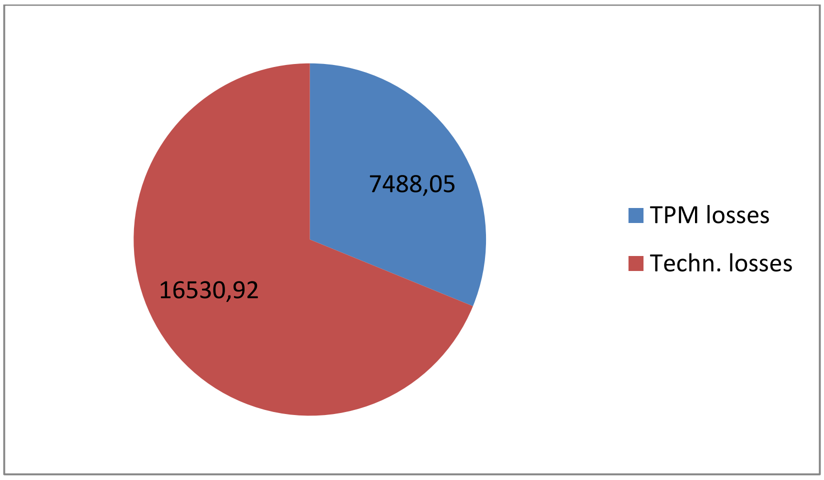

Figure 45: OEE losses (TPM, technical) in hours over all mechanical processing lines for 2014

If planned repair activities are just 25%[32] faster than unplanned repair activities and 50% of all unplanned maintenance activities can be predicted, in the future, 2066 working hours can be saved. This will increase the overall OEE immediately because these 2066 hours are hours of production loss (downtime). This can be seen in figure 46.

[32] Value assumed from the processes in figure 46

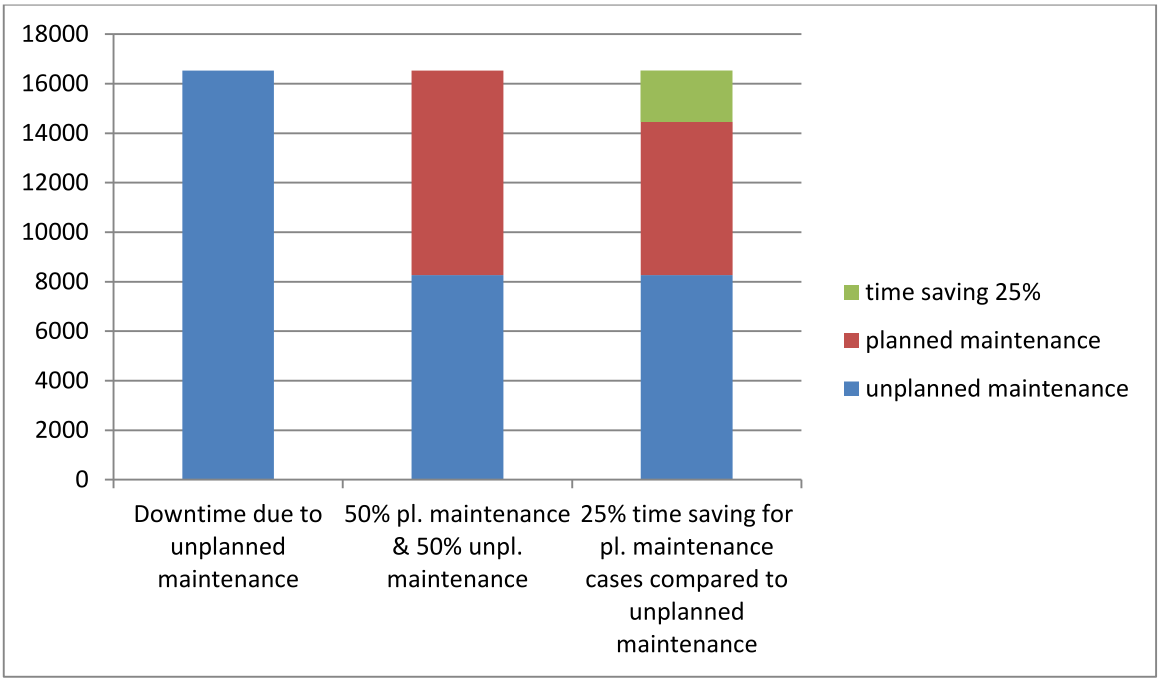

Figure 46: planned maintenance unplanned maintenance and time saving due to a predictive maintenance strategy in hours

By implementing such a strategy and reaching the set goals from figure 46, the OEE can be improved. The assumptions made in figure 46 can probably be excelled. Therefore a short example for the high potential of predictive maintenance will be given by taking the assumptions from figure 46. Technical losses can be reduced from currently 7,03% to 4,71%. That means an increase of the OEE value by 0,88%. The technical losses will decrease by 2.32% if two thirds of all unplanned maintenance activities can be predicted and the actions will take just the half time of unplanned maintenance activities.

Technical OEE losses (all mechanical production lines 2014)		
Technical losses 2014 in percentage and in hours	7,03%	16530h
Reduction of unexpected maintenance	0,88%	2066h
New technical losses	6,15%	14464h

Table 11: Increase OEE by implementing a predictive maintenance system

5.1.2 Maintenance Hours performed by the Plant Service Maintenance Crew[33]

The amount of maintenance hours performed by the plant service in 2014 illustrates the need of a predictive maintenance system too.

Planned Maintenance Activities at mechanical processing Lines:

Summer company holidays:	7621h
Winter company holidays:	4688h
TPM shifts (all mech. processing lines)	1795h
Sum:	14104h

Unplanned Maintenance:

All lines:	39675,5h
All mech. Processing lines:	38553,5h

Critical at the unplanned maintenance hours carried out by the plant service maintenance staff is, that roughly 3000 hours are not assigned to any line or production asset. There is no or just very rarely a way to allocate this to a specific asset. (a maintenance software can improve the processes)

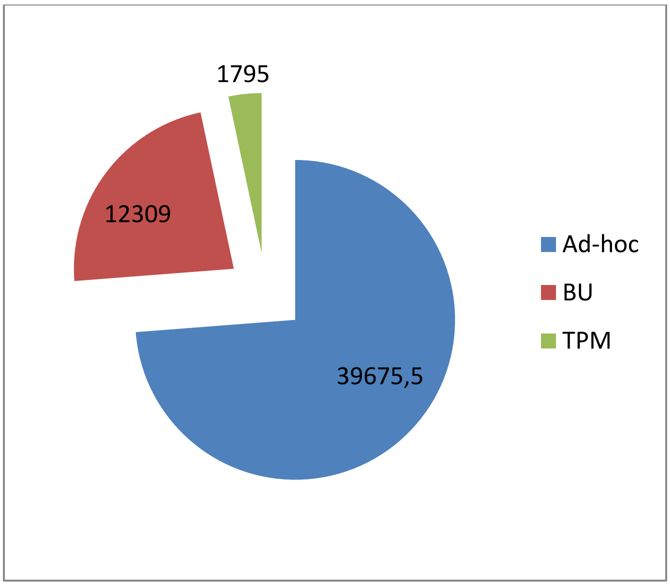

Figure 47: Overview of all WS hours 2014

Unplanned maintenance hours dependent on the task are almost several times as high as the amount of hours for planned maintenance activities. Reducing the hours of unplanned maintenance is the goal for the future. This goal can be reached by implementing a predictive maintenance strategy.
Advantages for increasing planned maintenance and decreasing unplanned maintenance activities:

[33] All data are from analyzing AUDI internal documents

- It reduces machine downtime
- It increases OEE
- It releases human resources (WS)
- It increases flexibility

5.1.3 Further Reasons

Costs of Production Loss due to unplanned Downtimes:
If due to unplanned downtimes the required amount of parts cannot be produced and the purchase from external suppliers is required it causes enormous additional costs.

A short example[34]:

Production volume per day (24 hours):	1000ZKG/24h
Costs of internal production[35] :	148,32€
Purchase costs:	296,64€

Costs for one hour of loss of production:

$$Costs = \frac{Required\ production}{Production\ time} * Purchase\ costs$$

In this specific case a loss of one hour production time will cause costs of 12360€. The ZKG is the most expensive part of the produced parts, for the connecting rod which is the cheapest part the costs will be not that high. Therefore avoiding the loss of production is a main objective and a huge cost factor.

BDE System:
One further reason for implementing a predictive maintenance strategy is that the product data acquisition program is already implemented at the production lines. This data can be analyzed. After analyzing the data it should be possible to predict failures based on the type of the error message and the frequency of occurrence. If further actions for the prediction of failures like vibration analysis are necessary they have to be defined after the data analysis is done.

5.2 Structural Organization

Keeping the hybrid organizational structure of centralized and decentralized parts is absolutely desirable. Such an organizational form combines the advantages of both organizational structures and at the same times minimizes the disadvantages of each structure.
Unplanned maintenance activities require the highest level of flexibility from the organization. In case of an unplanned breakdown the organization has to react under certain circumstances to specific events within an adequate time frame and within specified limits. The need of organizational flexibility will decrease if unplanned maintenance activities can be avoided or minimized. The aim of predictive maintenance and condition monitoring is to avoid such critical

[34] Information are from AUDI internal documents
[35] ZKG R4 Diesel

events. At the moment the factor of uncertainty, is that it is hard to predict which conditions can be monitored and how solid this data will be in the future.
The decision about the number of employees belonging to the centralized and decentralized maintenance team is an important one. Besides the number of employees their qualification plays an important role as well. It is a factor which influences the organizational flexibility enormously. The investigations have shown, that the plant service (WS) capacity in particular the human resources compared to the huge production is quite low.
For finding the right structural organization the spare part storage (Bemi storage) the centralized WS as well as the organization of the production line were under investigation.

5.2.1 Spare Part Warehouse

The investigations have shown, that the spare part ordering process and for the structural organization especially the spare collecting procedure, are critical steps.
Picking up the spare part at the spare part warehouse has to be done by the line maintenance employee (defined in the TPM handbook) from the department for which the spare part is determined for. Whether this task is carried out by the responsible line IH or by a machine operator cannot be clarified by 100%. It is a fact, that for picking up some special spare parts the know-how and the expertise of an IH employee is required to validate that the new spare part is the right one. The workforce of maintenance employees is very valuable because they have special skills. As mentioned in chapter 3.2.1 the way to the spare part warehouse can be very long depending on the location of the production line.
While the maintenance worker is on the way to pick up the spare part he is missing at the broken-down machine. This fact will increase the machine downtime and the MTTR and will decrease the OEE in general. If the spare part is delivered by the spare part warehouse, many hours of downtime will be saved aside from the fact that the maintenance engineer will be unburden too. While the spare parts are delivered, the maintenance worker can prepare activities at the machine or disassemble the broken part already until the new spare part arrives at the machine.
This action will also reduce the downtime and will increase the OEE value for unplanned repair cases. In figure 48 the two processes are shown. The first one is the current process and the second one represents the new process.

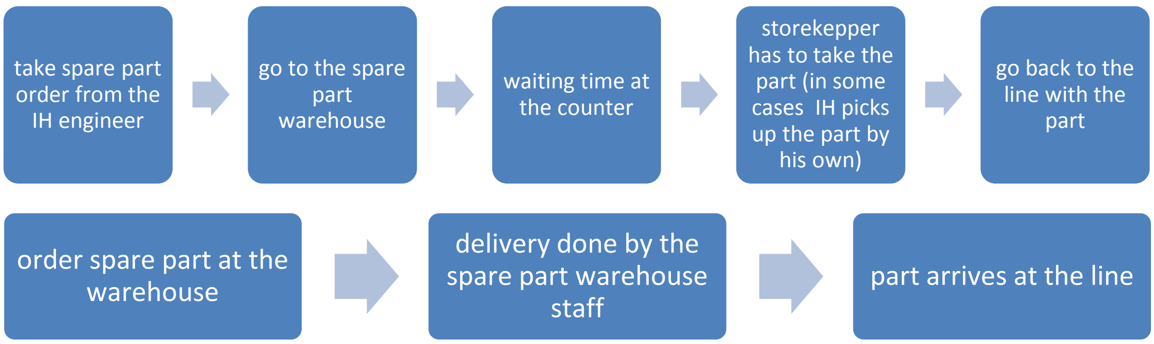

Figure 48: Spare part delivery vs. collection by the maintenance engineer

The following formula shows the amount of hours which can be saved if a delivery service will be implemented.

$$Time\ saving = Number\ of\ collections * Average\ duration\ of\ collection$$

The difficulty for calculate the time savings for maintenance engineers if the spare part is delivered by the spare part warehouse staff is, to figure out a correct average collection time. Factors which influence the collecting time are:

- Distance from the production line to the spare part warehouse
- Type of mobility (by walking, by electro mobile, etc.)
- Type of spare part (how easy and fast to transport)
- Waiting time at the counter
- Time for obtaining the part from its storage location

Spare Part Delivery for unplanned Maintenance Activities:
The following calculation visualizes, how much machine downtime a spare part delivery done by the WS, can save. Per year approximately 256000 spare parts are picked up at the spare part storage (Bemi). Thus, the assumption is, that on average 10 parts per issue are taken. That means, that 25600 times a person (line IH employee) has to go the storage to pick up the needed parts. A further assumption is that of out those 25600 storage issues, 20% are caused by an equipment breakdown (probably the number is much higher). The other amount of spare parts is for planned maintenance activities which are not so critical. Therefore, 5120 times it will cause additional downtime, if the IH employee from the line is picking up the spare part. Assuming an average time for picking up the spare part of ten minutes, it means 850 hours are wasted for picking up the spare part. If the spare parts gets delivered by the Bemi storage in the meantime disassembly activities can be done by the line IH employee. That means, that the saved 850 hours can be doubled because the time can be used “twice” by the IH worker. That means, that 1700 hours of downtime can be saved over a year.

$$time\ saving = \frac{256000 stock\ issues}{10 parts\ per\ issue * 20\% break\ down} * 10\,\mathrm{min\ average\ pick\ up\ time}$$

Benefits:

- Relieve work load from the line IH
- Reduce technical losses by 10,32%
- Increase OEE by 0,73%

5.2.2 Organization of the Plant Service

The plant service (WS) as already mentioned represents the decentralized organization. The main role of the WS is ad-hoc maintenance. 74% of the all performed activities are ad-hoc. A predictive maintenance strategy will also improve the WS efficiency. Now some numbers about the WS will be presented which show that the organization already has reached the capacity limit[36].

Additional working hours per month:	~200h/month
Additional working hours during summer company holidays:	~4000h
Additional working hours during winter company holidays:	~2000h

[36] Audi internal information

Due to the fact, that the plant service is overloaded already some jobs cannot be carried out and waiting times for the production lines occur. If the production is down each addition minute of downtime causes cost and has to be avoided.

Waiting time occurs, if at one line a failure comes up and the line maintenance staff is not able to solve the problem. Then the support of the WS is often needed, but if all plant service maintenance workers are busy, waiting times are the result.

Waiting Time 2014:
In 2014 there were 160 reported cases where the support of the WS was required but not immediately available. Waiting time is defined as the time period from the request until capacities are available to give support to the production line.

Sum of waiting hours:	633h/year
Number of cases:	160

That means, that the average waiting time in 160 cases is approximately four hours. By remembering the calculated value for one hour production loss at a ZKG line in chapter 5.1.3, it is obvious, that waiting times have to be avoided where possible.
All these factors would justify an increase of the human resources at the plant service. Setting actions to disburden the WS is another possibility.

Benefits (by avoiding waiting time):
- Increase OEE about 0,27%[37]
- Save costs for loss of production

Expenses for external Maintenance:
External companies improve flexibility for the maintenance, because they can be “activated” if their competence is needed (reacting time is critical) and they have to be paid just for the tasks carried out. They cause no fix costs but the single working hours are quite expensive compared to internal wages. Outsourcing tasks which can be done in house due to capacitive reasons causes high additional costs.
External companies which are required for maintenance tasks at AHM are located across Europe. Due to these distances to AHM very long waiting times can be the case.
Disburdening the plant service and the line maintenance staff will reduce the expenses caused by the use of external companies.
The overall external maintenance costs in 2014 including materials and working hours were roughly 20million €. It can be assumed, that the higher amount of costs are personnel costs because the spare part availability at the spare part storage is about 99.7%[38]. Some of those activities have to be outsourced, because they can only be performed by them (annual service due to warranty). A big amount of external hours is used because of a lack of internal capacity. Two million euros can be saved by doing just 10% of the external maintenance activities in-house. On average one hour of support given by Grob (many assets at AHM are from this manufacturer) costs 197€ onaverage, just personnel costs. Compared to roughly 20€ an internal maintenance worker costs per hour makes the potential for decreasing maintenance

[37] Calculation in the attachment
[38] Information from AUDI intrnal document

costs obvious. In figure 49 the costs (in million euro) for external maintenance assigned to the segment can be seen.

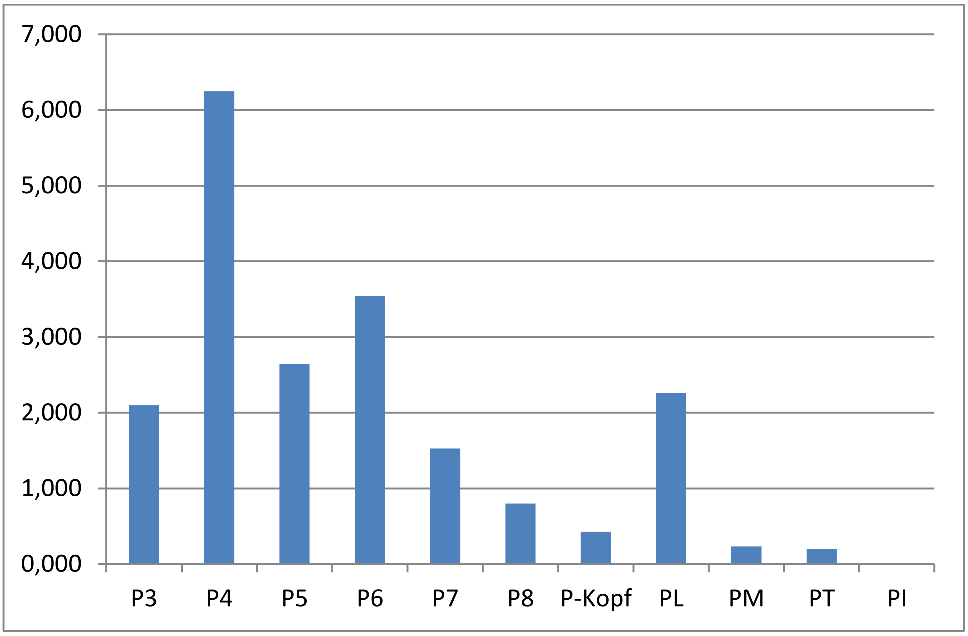

Figure 49: Costs of external maintenance 2014 in million € (sum ~20million €)

5.2.3 Production Line Organization

As already mentioned, a hybrid strategy of centralized and decentralized maintenance teams combine the advantages of both organizations. While a decentralized organization allows a very fast and target oriented process, the decentralized organization mainly brings a lot of flexibility to the organization. A further point for using the decentralized organization is, that a sense of responsibility from the decentralized maintenance people for the line is better than from external maintenance workers. By bringing the huge variety of different machines and manufacturers from chapter 3.1.4 back in mind it is obvious, that each line has its unique problems. For the centralized maintenance employees it is nearly impossible to know all line specific characteristics. Therefore some specific failures which are aware to the line IH employee can be solved by himself very quickly, because he knows what to do. For an employee sent from the plant service to the production line, who is not familiar with the line, it will take much longer to solve the problem as it would take if the line IH would solve the issue. The production line (and in particular the maintenance engineers and employees) represents the decentralized part of the maintenance organization. The aim of the organizational unit to react quickly to certain events, works well. Even the communication, works basically well due to the short distances between the people involved. The communication to the centralized maintenance organization and to external companies has to be changed and improved in any case. How this can look like will be explained later in the thesis (Process organization)
The amount of maintenance people per line defined by the management is sufficient[39] if all positions are occupied and some improvements will be done (spare part delivery service). At

[39] Information from interviews concerning the number of line maintenance staff assigned to a production line.
Hollósi Gergö Balasz G/P3-13 Line Maintenance Engineer
Gabor Pasci G/P7-13 Line Maintenance Engineer
Karoly Hevesi G/P5 Head of Production Segment
Albert Fazekas G/PT Maintenance Manager

the moment there is a huge gap between the target state and the real state in the number of maintenance personnel at the production lines. This definitely has to be changed in the future As already mentioned in chapter 3.2.1.1 the number of approved amount of maintenance workers and the real amount of maintenance employees allocated to one production diverge considerably.

The sum of employees missing overall production lines is more than 30 which is nearly the same amount of IH employees belonging to the WS. It is obvious that by this lack of decentralized maintenance workers the work load for the WS is increasing, but the WS simply does not have the capacity to do all upcoming work. So that's one reason why a lot of work has to be outsourced even though the competences in-house would be there.

In order to verify the need for these line maintenance employees a correlation analysis was carried out.

Correlation Analysis:

"Correlation is a statistical measure that indicates the extent to which two or more variables fluctuate together. A positive correlation indicates the extent to which those variables increase or decrease in parallel; a negative correlation indicates the extent to which one variable increases as the other decreases." (Rouse, 2015)

"When the fluctuation of one variable reliably predicts a similar fluctuation in another variable, there's often a tendency to think that means that the change in one causes the change in the other. However, correlation does not imply causation. There may be, for example, an unknown factor that influences both variables similarly." (Rouse, 2015)

$$r_{xy} = (\frac{1}{n})\sum_{i-1}^{n}(x_i - \bar{x}) * (y_i - \bar{y})/(s_x * s_y)$$

High correlation:	0.5 to 1.0 or -0.5 to -1.0
Medium correlation:	0.3 to 0.5 or -0.3 to -0.5
Low correlation:	0.1 to 0.3 or -0.1 to -0.3

Chosen Variables for the Correlation Analysis:

The correlation analysis was done for two different types of production lines, for the ZKG and the ZK lines. These lines were chosen because of the complexity of the lines, the varying amount of maintenance staff at the lines and the overall number of lines. For a statistical certainty the number of lines is critical.

<u>Deviation of maintenance staff (from chapter 3.2.1.1)</u>

There is a deviation from the allocated to the real amount of line maintenance engineers. At some lines there are more maintenance workers and at other lines there are fewer maintenance employees than required. The goal is to figure out if this fact influences the OEE and the working hours done by the WS at these lines.

<u>Real vs. required OEE:</u>

For each line an OEE value is defined by the management. The deviation from the defined to the real OEE value is measured in percentage.

Working hours of the WS at the specific lines:
The amount of working hours performed by the WS for one year were collected and assigned to the specific production line.

Figure 50 shows the correlation of the OEE and the number of line IH for ZK and ZKG lines. In figure 51 the results from figure 50 are shown within one diagram.

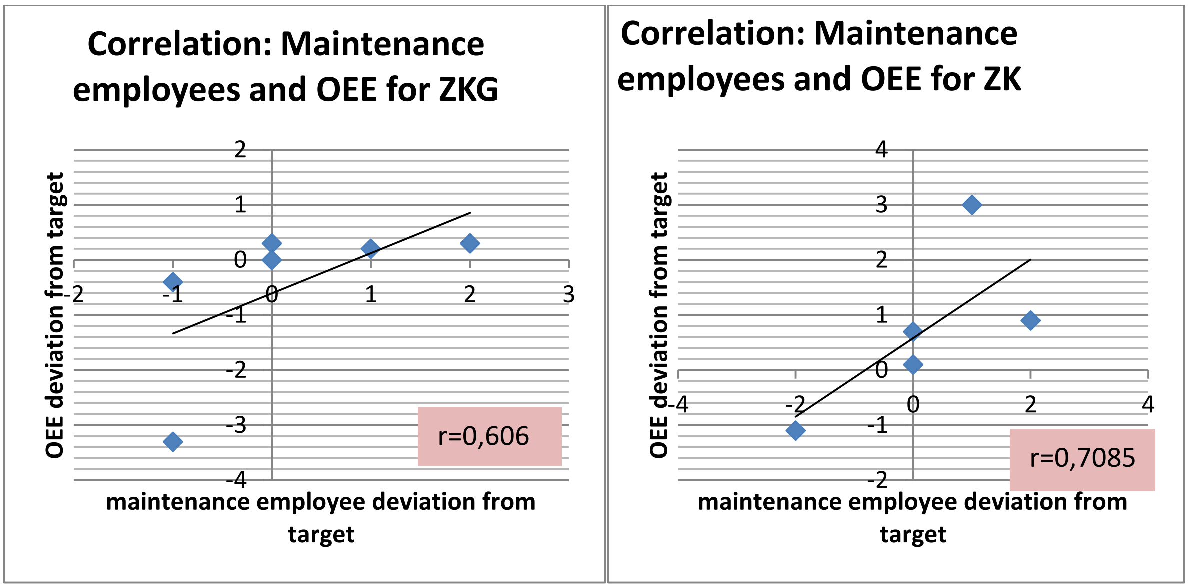

Figure 50: Correlation analysis, maintenance staff and OEE for ZK and ZKG separate

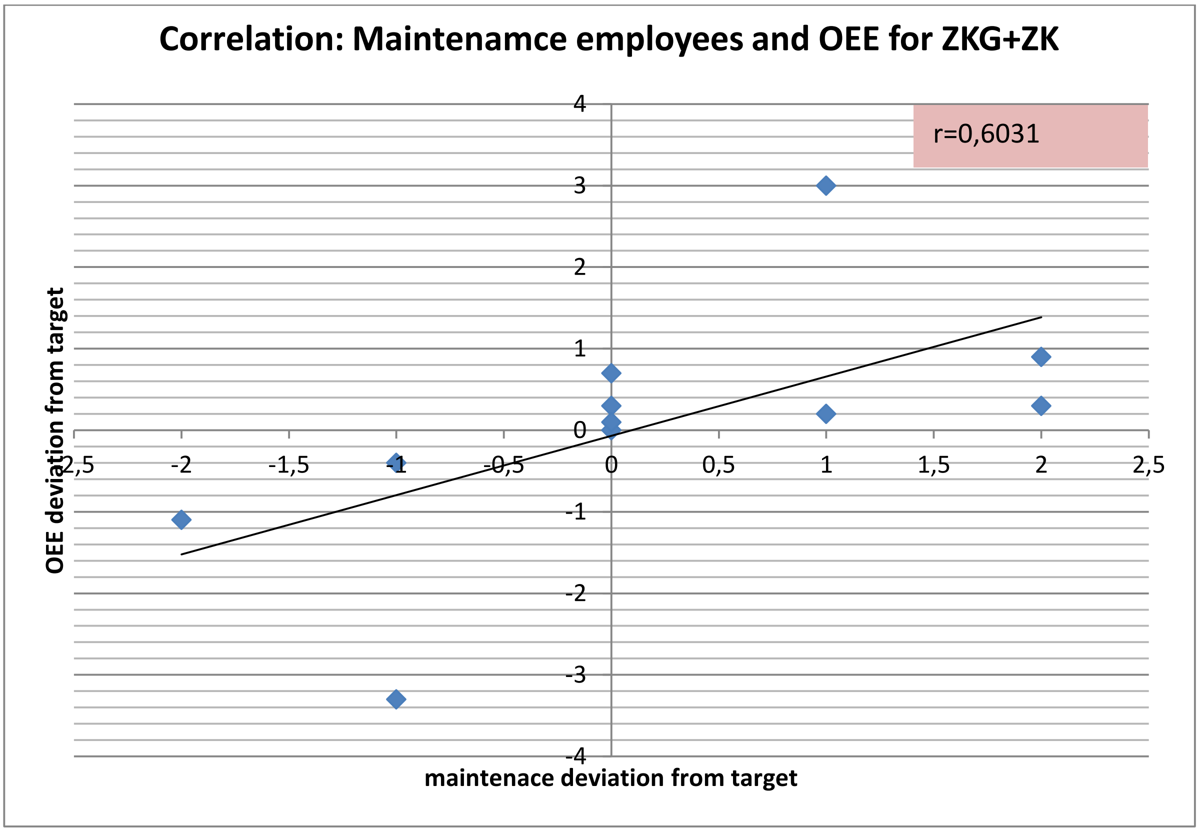

Figure 51: correlation analysis, maintenance staff and OEE for ZK and ZKG together

In figure 52 the correlation analysis for the performed maintenance hours from the WS and the number of line IH for ZK and ZKG lines is shown. Figure 52 combines the results made in figure 53.

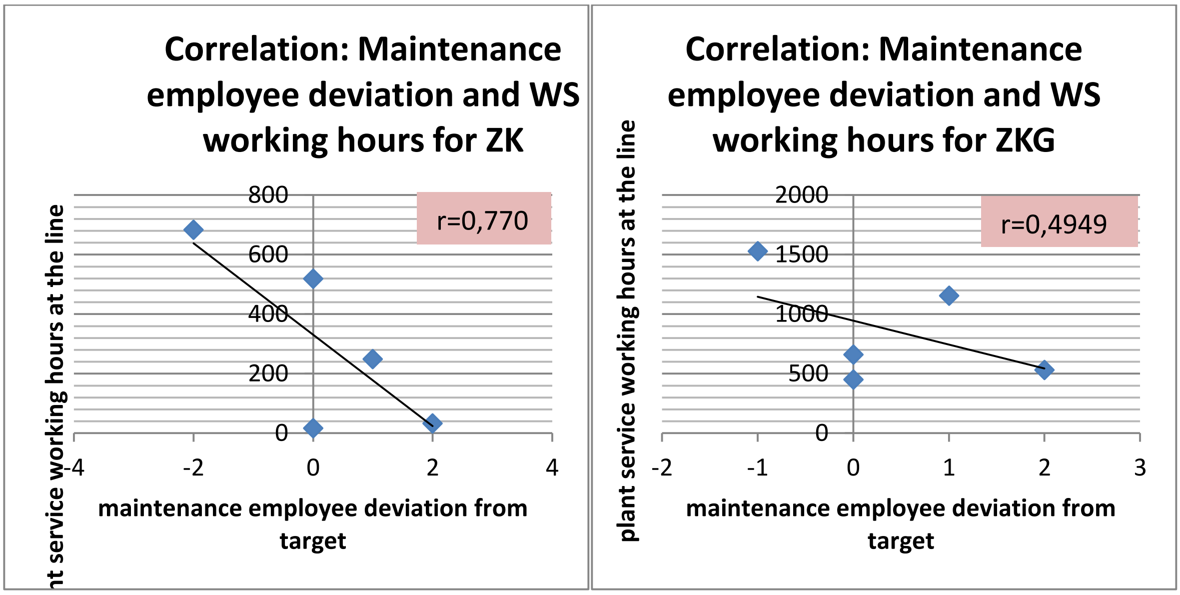

Figure 52: correlation analysis, WS maintenance hours for ZK and ZKG separate

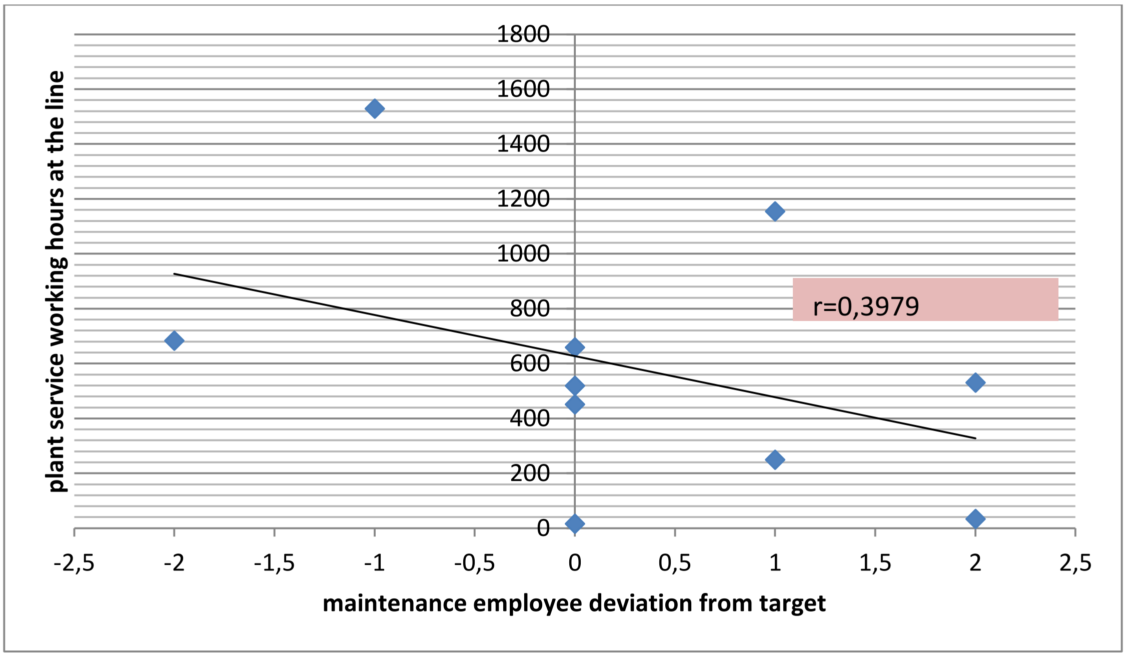

Figure 53: correlation analysis, WS maintenance hours for ZK and ZKG together

From this correlation analysis it can be seen that both, the OEE and the WS working hours are influenced by the number of line maintenance employees. With an increasing number of decentralized maintenance workers the OEE is increased. Each investigated line with the appropriate number of maintenance staff has reached the defined OEE target value. Even the required hours of WS support will decrease. This will disburden the WS and the flexibility of the organization will increase.

It furthermore relieves the maintenance engineer who is mainly responsible for the maintenance organization. It will be necessary to implement maintenance software which supports his actions and make the workflows more efficient.

5.3 Process Organization:

As already mentioned, a lot of time can be saved by optimizing the processes to reach a more efficient use of the available resources. To ensure more efficient processes, a digitalization of those documents and processes is essential and will be explained now.

5.3.1 Maintenance System

An easy-to-use software solution which combines all available data to improve the maintenance processes has to be the target. Therefore it had been decided to divide the processes up in already known “modules”. The system should contain models for:

- Autonomous maintenance
- Planned maintenance
- Unplanned Maintenance

Sub or supporting processes for main modules:

- Spare part ordering
- Staffing (access)

Such a system should support the people involved in the maintenance activities and not make their lives more complicated. The information and options provided by the system has to be divided in user groups. A line maintenance engineer requires options and information different to those for a machine operator. All orders of centralized maintenance staff have to be managed by a control center, where all incoming orders are processed.

Advantages such a system generates are:

- It simplifies and standardize the processes
    - Activities can be allocated to specific machines
    - Cost tracking for maintenance costs per asset
- It provides for efficient planning of activities
- It includes information from predictive maintenance system
- It is flexible in case of unplanned events
- It optimizes the route the IH staff

5.3.1.1 Autonomous Maintenance

With the new predictive maintenance strategy also information about how frequently autonomous maintenance activities have to be carried out will be generated. So a more frequent adaption of the TS02 is necessary. Doing these adaptions online in real time will shorten the time needed. The machine operator should have the possibility to provide information concerning the asset condition or unexpected incidents to the maintenance engineer. This information will support the planning of maintenance activities and is an additional source of information in addition to the predictive maintenance system.

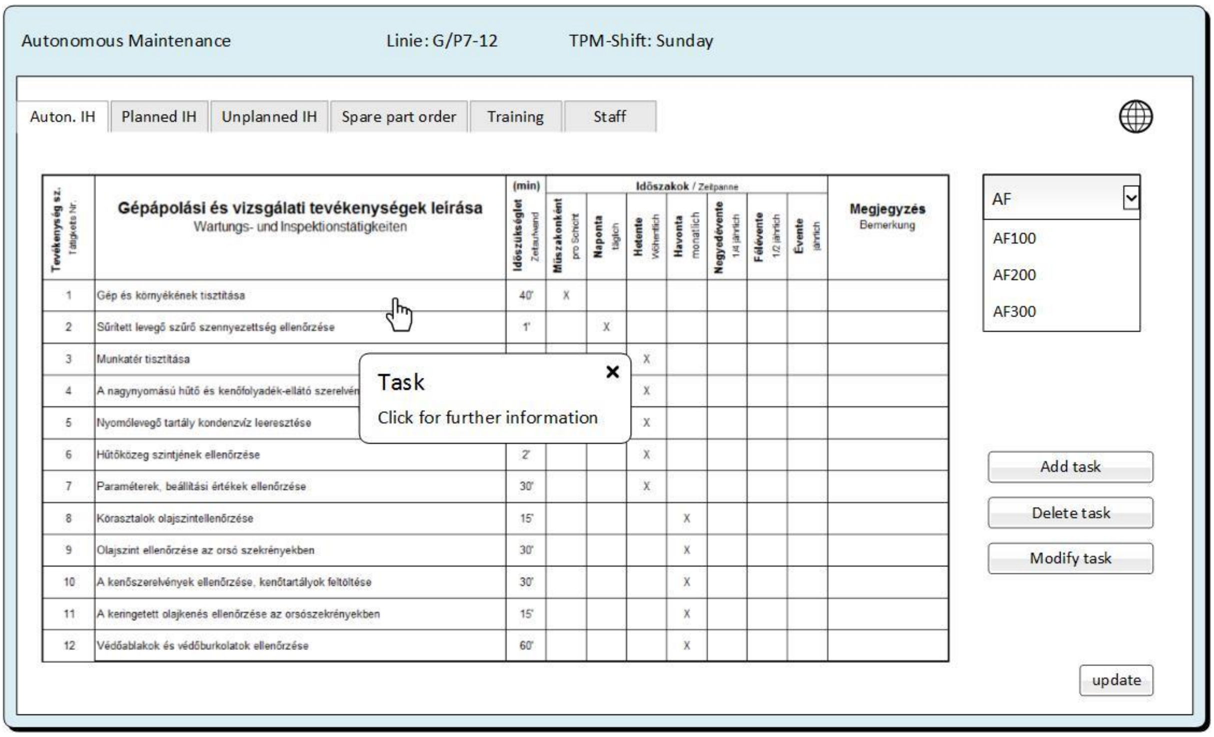

Figure 54: Input mask autonomous maintenance for the maintenance engineer

The TS02 Standard is digitalized and can be adapted easily by the IH engineer. The new standard can be sent to the production equipment in charge. The tasks are presented to the machine operator on the touch panel or via mobile devices. The tasks are presented by colors to the machine operator similar to the way it is already done at WinTPM. Information according to the task such as the working methods or the values for setting up an adjustment will be presented by clicking on the task. This improvement will reduce the time needed for searching the information within the TPM sheets. That will relieve the machine operator with the effect that he can focus on his main task, the production. This system should substitute all needed TPM sheets as well as the shift protocol.

Benefits:

- Fast and easy adaption of TPM standards (IH engineer)
- Information concerning the task are linked (no searching in the TPM sheets)
- Tasks cannot be left behind
- Tasks which are not done or done too late can be seen easily by the engineer
- Additional source of information for the maintenance engineer
- The digitalized data makes analyses easier
- Actions and the maintenance performance of similar lines can be compared easily

5.3.1.2 Planned Maintenance

By implementing a predictive maintenance strategy the amount of planned maintenance tasks will increase. Information and suggestions for maintenance activities from the predictive maintenance system should be given, to support the maintenance engineer in making the right decisions and for maintenance at the right time. Many of these activities require, support by the plant service or by external companies. In order to optimize communication, the communication in the future has to take place via this maintenance system and not by phone calls or e-mails. The advantage is that the task to be done can easily be stored and retrieved by the date when it has to be carried out or by its urgency. Providing the needed information directly to the employees` mobile device will increase efficiency, because he has all needed information with him.

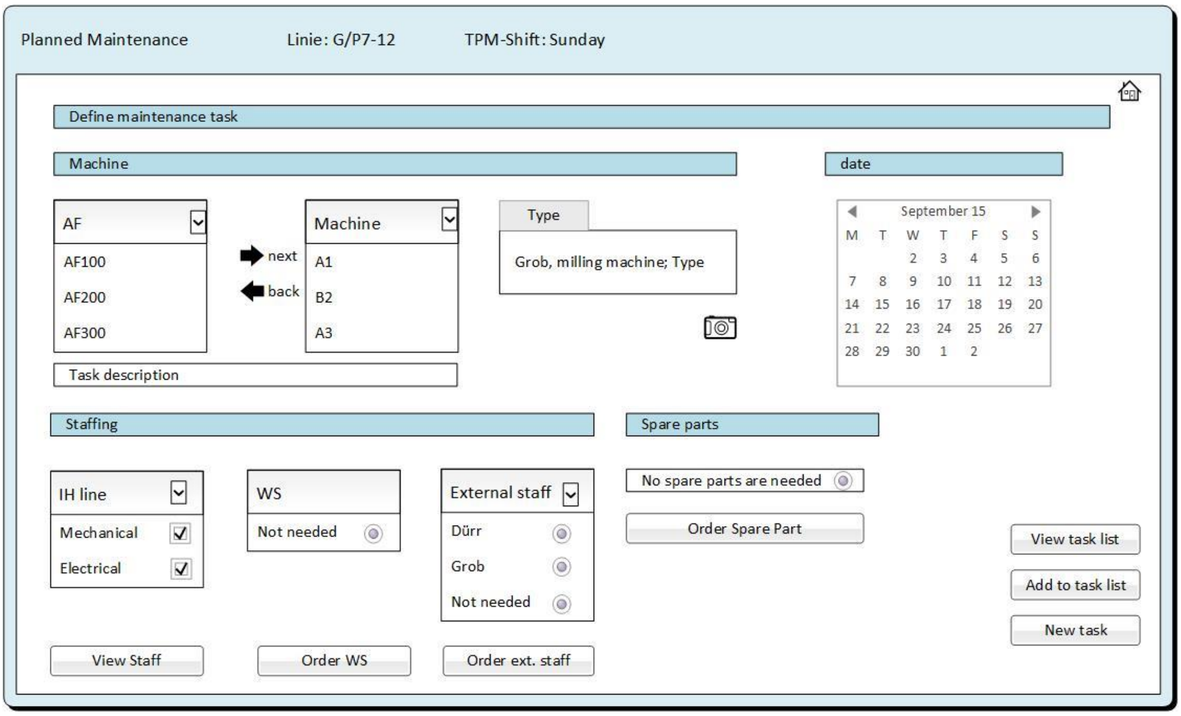

Figure 55: Planned maintenance mask for the line IH engineer

In figure 55 an example of how such an input mask for panned maintenance activities fort the maintenance engineer can look like is shown. The GUI (graphic user interface) for the maintenance workers has to look different and contains other information which are important for them. Information about the task, a task description and where and when the task has to be performed, are important for the maintenance employees. To log in and log off to the task will also be necessary. This provides additional information where and for how long which person is busy. How this will work out will be explained later on more in detail.

Benefits:

- Suggestions for maintenance activities from the BDE data analyzing are provided
- Uniform input mask
- Ordering spare parts, the technical service or external companies can be done
- Cost tracking is easier (all actions and spare parts can be assigned to an asset)
- Working hours and spare parts can be assigned to a specific asset
- Communication becomes more efficient
- The task “status” is visible

5.3.1.3 Unplanned Maintenance

The description is done mainly for cases where the WS is required, because this process at the moment does not work very well and is not uniform. Therefore a unification and a simplification of this process is essential.

Similar to the planned maintenance ordering procedure there is an input mask for unplanned maintenance activities. All relevant information is provided to the plant service. With this information, the control center employee can treat the order. Important for this module is, that the staffing model is connected to the unplanned maintenance model and ensures a fast and efficient decision making. In the future it will be necessary to know at all times where the WS maintenance workers are. On which asset they are performing their task and how long it will approximately take. Therefore it is essential, that the employee logs in on the task and the asset he is working and if he has finished that he logs out. All this information whether the worker is available or not must be provided to the control center responsible. In the case, that a request from a prioritized line is coming the employee at the control center, he has to react to this event as fast as possible. Therefore information about how many maintenance people are available is necessary. If all are busy the information about the location and the task they are performing is absolutely essential to make the best and most efficient decision. In figure 56 a suggestion for the visualization of the information about the place and duration of the performance task is given. Information about how many employees and how long it will take can easily be seen within this graphic.
By clicking on the colored areas further information about the task is given. Which asset is affected what is the task about, how critical is the task and also the names of the employees carrying out the task are shown.

Figure 56[40]: Overview of all tasks carried out by the plant service maintenance staff

Benefits:

- Standardized
- Enables the allocation of working hours to lines and assets
- Effective decision making
- Efficient use of resources
- Overview of performed tasks
- Overview of where the IH employees are located at the moment

[40] MA (maintenance worker)

5.3.1.4 Spare Part ordering Process

The spare part ordering process should be possible in each of the main modules. For spare parts needed after an unplanned breakdown, a delivery service can be ordered additionally. For planned maintenance activities the needed spare parts have to be prepared in packages ready for collection on the desired date. To guarantee, that the right part is chosen, the spare part numbers have to be uniform and the workers at the spare part storage which are responsible for that task need specific know-how and trainings. A suggestion how such an input mask can look like is given in figure 57.

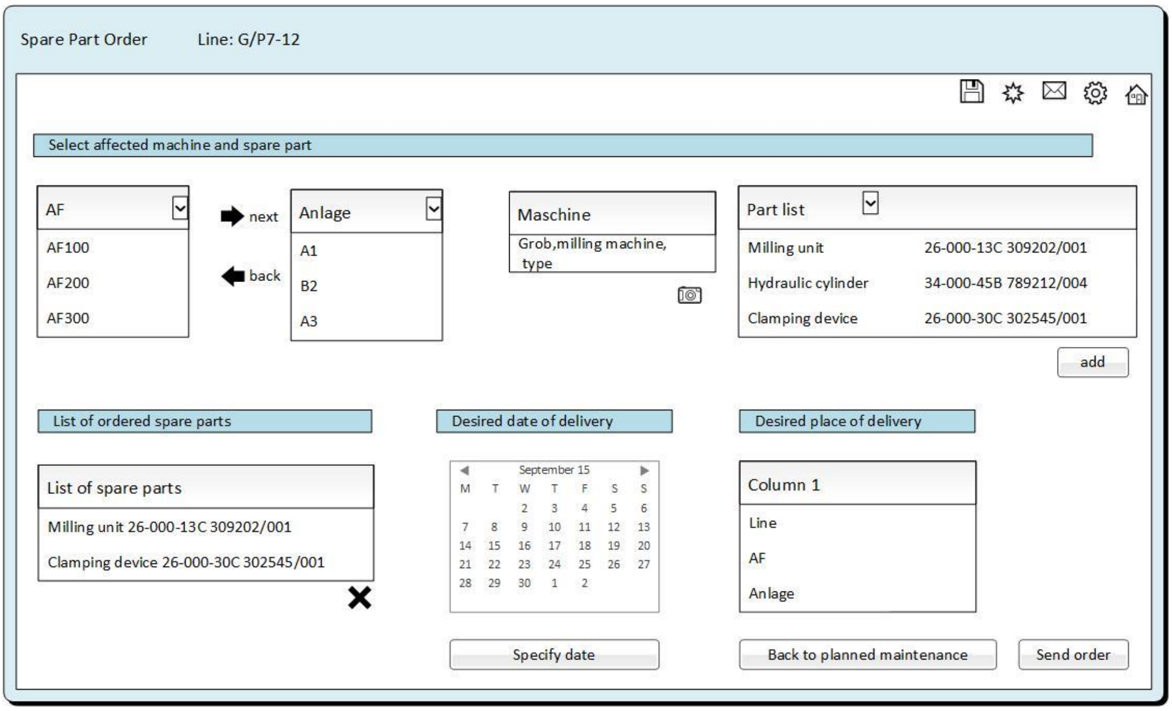

Figure 57: Input mask for spare part ordering

5.3.1.5 Staffing & Trainings

Trainings for a maintenance staff are essential for efficient maintenance. Technologies and service methods are changing. In order, to be prepared for these changes and to be able to carry out the required tasks, trainings for the employees are important. The skills and the trainings which a specific person owns as well as the planned trainings for the future have to be collected in a so called "qualification matrix". Within this matrix all done trainings and all planned trainings are visible. This matrix will support the staffing, because it can be seen which person is experienced in which task. Based on this information the staffing can be done very efficiently. Connecting the staffing module with the skill matrix is essential.

For efficient processes it is important to know:

- How many maintenance people are in-house
- Which skills do they have
- Which task are planned for them for this day
- Real time tracking where they are and which task they are performing

The current "system", that a sheet with the daily activities of each maintenance employee (WS) are put up down on the shop floor has to be substituted by the maintenance system.

Information about the date (month; day) the shift (06-18, 18-06) and the maintenance team (A, B, C, D) are visible on this sheet. Also a personnel identification number is recorded to allocate the tasks to one specific person (figure 58).
Further information which can be taken from this sheet are the line on which the task is performed, a short description of the task. The starting time and after finishing the task the time when the task has been accomplished. If a new request for plant service (WS) support is coming in, the engineer at the WS has to go to the shop floor to check on the actions which are currently carried out. Based on this information, decisions for further actions can be made. This process is very inefficient in particular with a potential increase of the number of the WS maintenance staff. This information in connection with the “skill matrix” has to be provided to the engineer to do a fast and efficient decision making.

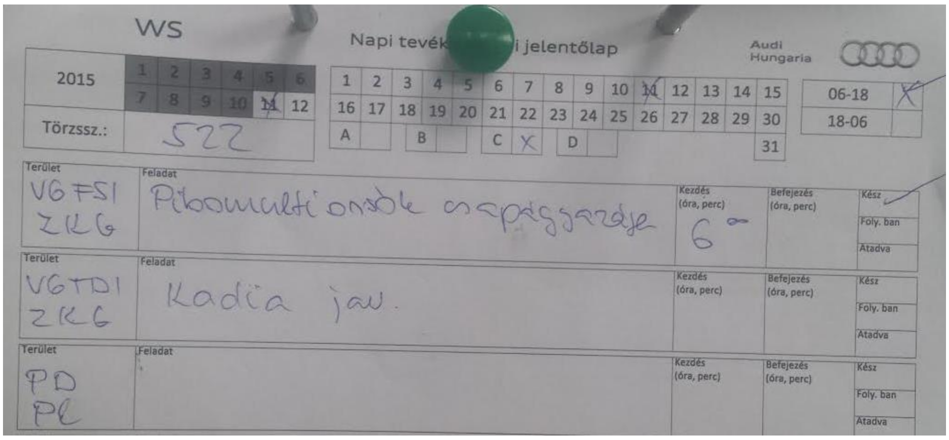

Figure 58: Staffing sheet at the WS shop floor; Audi internal document

5.3.2 Visualization

Mobile devices such as smart phones or tablets are the future for carrying out efficient maintenance. The possibilities such smart devices in connection with an appropriate maintenance system offer, are enormous. Information can be customized. Each user group gets the information it needs.
As already described, the system consists of different modules. Within one module different GUI´s for different user groups have to be set up. The engineer requires other information than a maintenance worker. Therefore also the information and how it is presented has to be different.

6 Summary

For an efficient production, maintenance is a vital process. Reliability in the production is an important indicator. In order to improve reliability and to increase the OEE value an appropriate maintenance concept is absolutely required. Even at AHM they are facing the challenge to improve the maintenance and boosting the production to the next level.

Developing a concept which meets the requirements best was the main target. To do so, at first a literature research was done. For the basic understanding as well as for the definition of important maintenance terms and indicators this literature research was essential. Strategies and changes in maintenance philosophy taken from the literature also provided another source of inspiration.

With this deeper understanding of maintenance, the current situation concerning maintenance at AHM was investigated. Starting with the general layout of the company by showing the immense size of the company, the structural organization and the process organization were under investigation as well. The used hybrid strategy between a centralized and decentralized organizational form was researched in particular. Which different maintenance activities have to be carried out and how does the processes look like has also been of main interest.

The know-how from the literature research and the analysis of the current practiced maintenance were the founding basis for the next step: defining requirements for a new maintenance organization. Beside general targets such as increasing the OEE and reducing overall maintenance costs specific requirements were defined as well.

After this step it was possible to develop a concept. The concept has been divided into three main fields:

- Finding an appropriate maintenance strategy
- Finding a structural organization which meets the requirements best
- Improve maintenance processes to reach the targets

The maintenance strategy was chosen by taking the requirements as well as the current organization into account. The currently practiced TPM maintenance strategy works very well in some aspects but has to be improved in others. By analyzing some facts, the need of a predictive or condition based maintenance strategy was the outcome. Supporting the already existing TPM strategy with predictive maintenance is absolutely essential for the future and has to be implemented. This strategy in the future will increase maintenance efficiency.

To find an appropriate structural organization different organizational forms have been investigated. For reducing the overall maintenance costs the best use of the given infrastructure and to avoid expensive rebuilding of the infrastructure was essential. The outcome was, that a hybrid strategy between a centralized organization (flexibility) and a decentralized (fast reacting times) organization fits best to the requirements and enables efficient maintenance.

The current existing processes can be divided into three main processes:

- Autonomous maintenance
- Planned maintenance
- Unplanned maintenance

and supporting processes:

- Spare part ordering
- Staffing (in particular for the centralized organization of interest)

All these processes at the moment are mainly carried out by using paper sheets and excel tables for defining, planning and carrying out maintenance actions. The main medium for communication between the people involved in the processes (within the decentralized organization, between the centralized and the decentralized organization) are E-mails and phone calls. For improving these processes a maintenance system similar to on the market available CMMC systems specified for the needs of AHM has to be implemented. Establish a system divided into different modules for the upcoming process has been the main idea.

6.1 Results

The requirements and targets:

- Increase OEE (reduce downtime)
- Reduce overall maintenance costs
- Improve communication and documentation
- Flexibility

can be reached by implementing a predictive maintenance strategy in addition to the existing TPM strategy. Therefore the data analyzation of the machine data to predict failures is a main tool to successfully implement a predictive or condition based maintenance strategy. Improve the existing hybrid strategy is a further necessary step. This can be reached by increasing the number of decentralized maintenance people to disburden the centralized organization and increase flexibility. To increase the number of internal maintenance staff will increase the OEE and flexibility and will have a positive influence on the overall maintenance costs. Implementing a maintenance software to make processes more efficient is another point of the concept. Main advantages of such a system are the improvement in communication and documentation between the different departments but also will have a positive impact on flexibility. In the following figure (figure 59) the three main pillars of the concept and the improvements and advantages they generate can be seen.

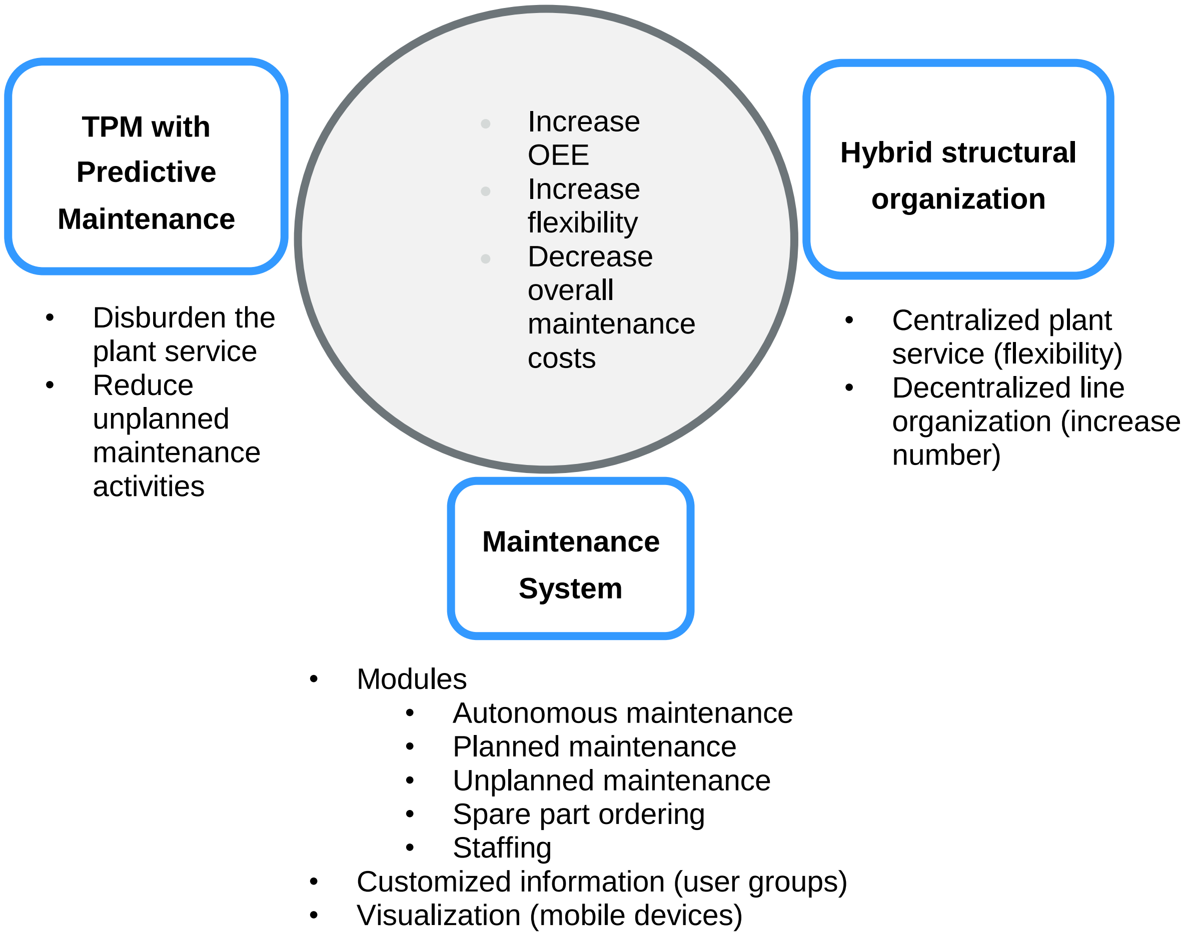

Figure 59: Concept-elements and results

6.2 Outlook

Some aspects were not investigated in this thesis but they can be a starting point for further investigations. How the spare part finishing department in the future should be organized and how the share between internal and external produced spare parts for a perfect combination between flexibility and costs should look like.
The concept was developed for implementing in the near future. Depending on how well the new organization - in particular the predictive maintenance system - will work, new investigations for the structural organization have to be done. Shifting decentralized maintenance staff to the centralized organization in the future can become an issue if the unplanned maintenance activities can be reduced dramatically. From the actual point of view, making assumptions how the development will be is not serious, therefore new investigations after a certain period of time will further improve maintenance.
This thesis was part of a profound project done by the Institute of Mechanical Engineering and Business Informatics (Institute of Graz University of Technology). This project also deals with the future maintenance organization within AHM with a main focus on analyzing data collected by the BDE system. This thesis is a preliminary work to this project. Findings and suggestions made in this thesis and from the project do not necessarily have to be conform.

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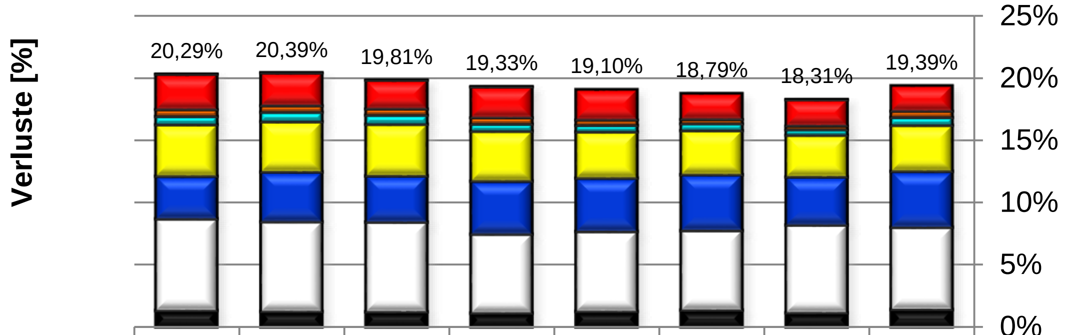
List of Abbreviations

A	Availability
AHM	AUDI HUNGARUIA KOTOR Kft.
BDE	Betriebsdatenerfassung
Bemi	Bertiebsmittellager
CMMS	Computerized Maintenance Management System
DOD	Department of Defense
i.e.	id est
IH	Instandhaltung, Instand Halter
KPI	Key Performance Indicator
KW	Kurbelwelle
MA	Mitarbeiter
MAMT	Mean Active Maintenance Time
MDT	Mean Downtime
MTBF	Meantime Between Failure
MTTR	Meantime to Repair
NW	Nockenwelle
OEE	Overall Equipment Efficiency
P	Performance
PL	Pleuel
Q	Quality
TPM	Total Productive Maintenance
WS	Werkservice
ZK	Zylinderkopf
ZKG	Zylinderkurbelgehäuse

Attachment

Attachment 1: OEE Losses 2014 and 2015



	2014 1.Q.	2014 2.Q.	2014 3.Q.	2014 4.Q	2015 1.Q	2015 2.Q	2015 3.Q	Ø Ziel 2015
Gesamtverluste	20,29%	20,39%	19,81%	19,33%	19,10%	18,79%	18,31%	19,39%
Versuchsfertigung	0,01%	0,01%	0,01%	0,02%	0,00%	0,00%	0,02%	0,00%
Qualität	2,81%	2,60%	2,29%	2,49%	2,45%	2,11%	2,10%	2,06%
Organisatorisch	0,56%	0,54%	0,50%	0,52%	0,44%	0,34%	0,32%	0,51%
Leistung	0,68%	0,76%	0,75%	0,59%	0,54%	0,56%	0,46%	0,66%
Werkzeug	4,12%	4,02%	4,11%	3,99%	3,72%	3,54%	3,35%	3,67%
Geplante TPM	3,45%	4,02%	3,74%	4,27%	4,29%	4,50%	3,87%	4,51%
Technische	7,36%	7,20%	7,20%	6,36%	6,42%	6,42%	7,06%	6,61%
Umrüsten	1,30%	1,23%	1,20%	1,10%	1,24%	1,32%	1,12%	1,38%

Attachment 2: Waiting Time Reduction (OEE)

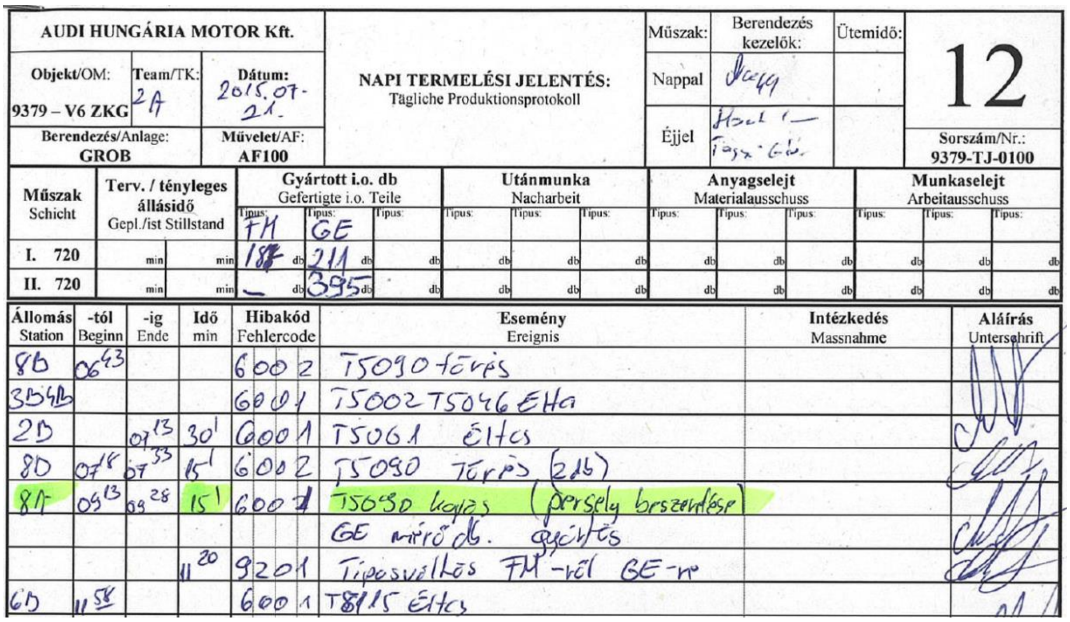
	%	hours
OEE loss	19,95	
Technical loss	7,03	16530,92
Waiting hours		633

	Overall in %	Technical loss
	7,03	100%
	0,07	1%
OEE loss reduction	0,27	3,83%

hours	%
16530,92	100
165,3092	1
633	3,83

If all waiting times are avodet the technical losses can be reduced by 3,83%. That means a overall OEE reduction of 0,27%.

Attachment 3: Shift Protocoll



AUDI HUNGÁRIA MOTOR Kft.			NAPI TERMELÉSI JELENTÉS: Tägliche Produktionsprotokoll	Műszak:	Berendezés kezelők:	Ütemidő:	12
Objekt/OM: 9379 – V6 ZKG	Team/TK: 2A	Dátum: 2015. 07. 21.		Nappal	[illegible]		
Berendezés/Anlage: GROB		Művelet/AF: AF100		Éjjel	[illegible]		Sorszám/Nr.: 9379-TJ-0100

Műszak Schicht	Terv. / tényleges állásidő Gepl./ist Stillstand		Gyártott i.o. db Gefertigte i.o. Teile			Utánmunka Nacharbeit			Anyagselejt Materialausschuss			Munkaselejt Arbeitausschuss		
			Típus: FM	Típus: GE	Típus:	Típus:	Típus:	Típus:	Típus:	Típus:	Típus:	Típus:	Típus:	Típus:
I. 720	min	min	187 db	211 db	db	db	db	db	db	db	db	db	db	db
II. 720	min	min	– db	395 db	db	db	db	db	db	db	db	db	db	db

Állomás Station	-tól Beginn	-ig Ende	Idő min	Hibakód Fehlercode	Esemény Ereignis	Intézkedés Massnahme	Aláírás Unterschrift
8B	06 43			6002	T5090 törés		
3B4B				6001	T5002 T5046 EHa		
2B		07 13	30'	6001	T5061 EHcs		
8D	07 18	07 33	15'	6002	T5090 Törés (2db)		
8A	09 13	09 28	15'	6007	T5090 kopás (persely beszerelése)		
					GE mérő db. gyártás		
		11 20		9201	Típusváltás FM-ről GE-re		
6D	11 58			6001	T8115 EHcs		

Shift protocoll

Attachment 4: FMZ Sheet

Einheitliche FMZ Regelung Zusammenfassung Mecha

Kategorie	Basis	Bereich						
		PL	NW	AVS NS	AVS NW	ZK	KW	ZKG
Messanlagebediener / Schicht	genehmigter Vorschlag von mech.Leiter von 2011	0	0	1	1	1	1	1
		PL	NW	AVS NS	AVS NW	ZK	KW	ZKG
Instandhalter / Schicht	genehmigter Vorschlag von mech.Leiter von 2011	1	1	2	2	2	2	2
		PL	NW	AVS NS	AVS NW	ZK	KW	ZKG
Qualifizierung (AT/Jahr/MA)	Fachliche Schulungen und Übungsschicht	2	2	2	2	2	2	2
		PL	NW	AVS NS	AVS NW	ZK	KW	ZKG
Werkzeugeinsteller / Schicht	genehmigter Vorschlag von mech.Leiter von 2011	0	0	1	0	0	1	1
		PL	NW	AVS NS	AVS NW	ZK	KW	ZKG
FTL / Schicht	Anzahl Schichten	1	1	1	1	1	1	1

Temporäre Genehmigung bis Erreichung von geplante Kapazität			
V-TDI NST	KoVOMo NST	V-TDI GW	KoVOMo GW
2	2	2	2
V-TDI NST	KoVOMo NST	V-TDI GW	KoVOMo GW
2	2	0	0

Kategorie	Basis													
TK		≤ 8	9	10	11	12	13	14	15	16	17	18	19	20
	Brutto MA Anzahl /Schicht	0,25	0,5	0,5	0,5	0,5	1	1	1	1	1,5	1,5	1,5	1,5
TK		21	22	23	24	25	26	27	28	29	30	31	32	
	Brutto MA Anzahl /Schicht	2	2	2	2	2,5	2,5	2,5	2,5	3	3	3	3	

FMZ Kategorie