Why fix it when it is not broken?

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ABSTRACT, The purpose of this dissertation is developing a maintenance strategy for the Central Department of the Unilever Nassaukade factory.

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Keywords
Maintenance plan, Preventive maintenance, priority maintenance, maintenance strategy, maintenance outsourcing

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Dear reader,

The thesis before you marks the end of many years at the Univeristy of Twente.

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LIST OF ABBREVIATIONS

CBM	Condition-based maintenance
CM	Corrective maintenance
CMMS	Computerized Maintenance Management System
IPDSS	Intelligent predictive decision support system
JIT	Just in Time
OEM	Original Equipment Manufacturer
PM	Preventive Maintenance
PPM	Periodic Preventive Maintenance
SGA	Small Group Activity
TPM	Total Productive Maintenance
WCM	World Class Manufacturing
WIP	Work in process

INTRODUCTION

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The function of maintenance has changed dramatically over the past decades. Initially, operating equipment was run until it broke down. At that point the asset was fixed or replaced.

This can be seen when looking at equipment from the industrial revolution; the over-engineering of that time meant that the machines have a very long operating life, with many of them still operational today.

Later, with equipment being capable of more and more production, the need for preventive maintenance rose. This meant that maintenance engineers preventively replaced key wearable components in order to ensure availability of the machine.

This idea rose to strategic maintenance where the cost of maintenance was offset to the benefit of asset availability.

As a part of this strategic maintenance, operators were involved in conducting maintenance to the machines they worked with. No longer was the relationship between maintenance and operators “I break, you fix”, but rather a cooperation between the two was created to improve the useful life of the machine.

The problem with this is what tasks should be assigned to the operator, and what maintenance tasks are better conducted by specialized maintenance engineers.

Another possibility for organising maintenance is to outsource the maintenance activities to a specialized party. This can, however lead to the leaking of company trade secrets, or a dependency on the external maintenance party allowing them a very strong position when negotiating the terms for a future contract.

For this thesis, I looked at the maintenance department at Unilever Sourcing Unit Nassaukade. Then, to compare the data, I sent surveys to the maintenance department of comparable Unilever sites, and compared my findings with what I found at Unilever Sourcing Unit Nassaukade.

AN INTRODUCTION TO UNILEVER NASSAUKADE

Unilever Netherland Food Factories BV Sourcing Unit Nassaukade (SUNK) produces margarine and margarine derivatives like liquid margarine at the Nassaukade in Rotterdam since 1891 when it was founded by Simon van der Bergh. Later Simon van der Bergh collaborated with Anton Jurgens to become van der Bergh and Jurgens, or as it was called 'the Blue Band factory'. Together van der Bergh and Jurgens had many margarine factories in Europe under the name 'Margarine Union'. Unilever was formed in 1935 when the Margarine Unie and Lever Brothers, who produced soap in the United Kingdom and at locations on the European Continent, decided to strengthen their position by merging into one company; Unilever. The current factory has grown through the years, and its original lay-out has been expanded to an iconic site on the river Maas, especially with the iconic, 133-meter-long office building that was constructed over the factory.

Presently Unilever is a multinational consumer goods factory that produces food and drinks, personal care products, and cleaning products, and is organised in four main divisions; Personal Care, Foods, Refreshment, and Home Care. Personal Care produces and sells skin and hair care products, deodorants, and oral care products. Foods produces soups, bouillons, sauces, snacks, mayonnaise, salad dressings, margarines and spreads. Refreshment produces and sells ice cream, tea-based beverages, weight-management products, and nutritionally enhanced staples sold in developing markets. Home Care produces and sells powders, liquids and capsules, soap bars and other cleaning products.[1]

Unilever's mission statement is

"to add vitality to life. We meet every day needs for nutrition, hygiene and personal care with brands that help people feel good, look good and get more out of life."[2]

This mission statement allows Unilever to continue operating according to long-held principles with the objective of value creation for all its stakeholders.

The Sourcing Unit Nassaukade produces approximately 200,000 tons of margarine and margarine derivatives annually which is sold at 19 different countries in Europe. Among the brands produced at this facility are Becel, Blue Band, Bertolli, Croma, Zeeuws Meisje, Planta, Rama, Flora, Fruit d'Or, and Solo. At 2008, the product portfolio has expanded with peanut butter when the production of Calvé peanut butter was moved from Delft to Rotterdam Nassaukade. Currently 10,000 tons of peanut butter and sate sauce are produced annually, almost all produced for the Dutch market.

The vision of Unilever Sourcing Unit Nassaukade is

"*We care for each other's safety and health. We are proactive, show ownership. We continuously improve with the aid of World Class Manufacturing (WCM), we want to be the best. We are passionate, trust and support each other. We keep commitments, and respectfully address each other on them."*

The Sourcing Unit Nassaukade employs around 240 employees, whose tasks range from production operator, quality control, maintenance, safety engineers, project management, planning, finance, human resources and information technology.

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[1] Unilever annual report and Accounts, 2015.
[2] Unilever, 2017.

AIM AND SCOPE

This study was conducted on the Central Department of Unilever Sourcing Unit Nassaukade. The Central Department starts with the raw materials and ends with the delivery of semi-finished goods to the production and packaging departments. The process of the Central Department is divided in three sub processes;

The intake and storage of ingredients, the production and refinement of semi-finished products for the production and packaging department, and the distribution to the premix tanks.

The Central Department was reorganized in 2015, as part of a €7,5 million cost saving programme, reducing its staff from 15 to 9 people. The available time for maintenance was further reduced when the occupation was reduced from a 7-day 5-shift system to a 5-day 3-shift system. The autonomous maintenance conducted by the operators usually was planned on the weekend. This required less rigor when planning for maintenance stops. The new system reduced the time allowed from maintenance from 2,800 hours per year, to 336 hours. This is 12% of the previously allotted time for maintenance, which has a serious impact on the maintenance planning and scheduling.

As a result, additional attention was on the structure and strategy of maintenance, now that there were significantly fewer resources available for conducting maintenance.

weekend days	shifts per day	hours per shift	total hours	2 man occupation	total available hours	occupation 15 operators	per operator
2	2*	7	1400	2	2800	15	186

days	shifts per day	hours per shift	total hours	2 man occupation	total available hours **	occupation 9 staff	per operator
2	3	7	168	2	336	9	37
2	1	7	56	4	224	-	-

days	shifts per day	hours per shift	total hours	2 man occupation	total available hours **	occupation 9 staff	per operator
1	1	7	63	4	252	-	-

In addition to the available maintenance hours in-house, certain maintenance tasks were outsourced. For this end, 224 + 280 hours of third party maintenance were planned. The available hours of third party maintenance were sourced at eight different parties, for the maintenance of specialized equipment where there wasn't the required in-house know-how, and non-rountinuous maintenance.

This brings the total number of maintenance hours at the Sourcing Unit Nassaukade for 2016 on 812 hours.

These changes greatly impacted the resources available for maintenance at the Central Department, forcing the organization to increase the efficiency on how these resources are used.

Table 1 Reorganisation Maintenance

PURPOSE

This thesis will focus on the different maintenance strategies at the Central Department of Unilever Nassaukade.

As described earlier, this department was recently reorganised, with great reduction in personnel and time availability. This reorganisation was cutting a great proportion of the available staff and time for maintenance.

Currently, maintenance at Unilever Nassaukade lacks proper definitions of maintenance tasks conducted at the factory. Defining the tasks required to maintain the operating equipment can be used for the management of these tasks. By defining what tasks need to be conducted to maintain an asset, the maintenance manager can create a schedule for maintenance to ensure proper service levels for all assets within the factory. Another side of defining a maintenance system is the possibility to check if certain maintenance tasks have been neglected for too long. Thirdly, these definitions can be used for both the training of new maintenance employees, ensuring continuity, as well as allowing maintenance engineers to take tasks over from colleagues when they are otherwise involved, or in case of sickness.

A set of clearly defined tasks can be used to get clear picture of all maintenance tasks conducted in a department, which can be used in the creation of a maintenance schedule and strategy. In this strategy, corrective, preventive, and opportunity maintenance policies can be mixed to optimise the use of the available resources in the maintenance department.

Creating a system for using the maintenance opportunities that arise during production, or while conducting maintenance on another part of the production line. The lack of good definitions of maintenance tasks, and their representative priorities disallows both to correctly estimate what task should be conducted as an opportunity for maintenance arises, and makes it difficult for new employees to comprehend what maintenance should be conducted on equipment, how frequent it should be done, and how the maintenance task should be executed correctly and safely.

To remedy this problem, Unilever Sourcing Unit Nassaukade has asked to create a system with proper maintenance task descriptions and associated priorities. This system can then be implemented in their Computerised Maintenance Management System (CMMS) and used in both the forming of the maintenance strategy, and reaction on opportunities for maintenance.

During my research I studied how the CMMS was used in the organisation of maintenance, and what needed to be filled in. With this, I aimed to create a complete picture of the scheduled maintenance in the central department, that could be used not only to document what maintenance was conducted, but also what the maintenance budget for the central department needed to be while ensuring maximum availability of the operating equipment.

RESEARCH QUESTIONS

The goal of this research is to define the tasks and other work in maintenance at Unilever Sourcing Unit Nassaukade to form a well-balanced maintenance strategy. This strategy consists out of the different types of maintenance conducted, depending on the service levels and strategic importance of the asset to be maintained. In order to produce a maintenance strategy aligned with the needs of the factory, three main challenges are formulated;

1. How can the maintenance strategy be improved to optimize the use of current available resources?
2. How can a mix of corrective, preventive, autonomous and contract maintenance be used to maximize the capacity of maintenance resources?
3. Does the use of contract maintenance decrease the need of corrective maintenance?

In answering these three research questions, this dissertation hopes meet the desired research objectives;

1. to form a usable maintenance model that can be applied to the current maintenance strategy
2. to improve the effectiveness of the maintenance conducted.
3. To improve the manageability of maintenance conducted in the Central Department of Unilever SUNK.

1. METHOD OF THIS CASE STUDY

1.1 My role at Unilever Nassaukade

1.1.1 Identifying unused assets

The first assignment I received at Unilever Nassaukade was to document the unused operating equipment that was stored after its use. These machines varied from conveyors to complex production equipment with competitor-sensitive properties.

The first step was to identify what was known about the equipment in the warehouse. There was a preliminary report made a year before the start of my assignment on what was in the warehouse. However, this was a quick summary, and resulted in a simple list.

With this list, I started digging to find the information in the system on the origin of these machines. Most of the machines were unknown, but with calling and emailing the few contacts I found that could tell me more on the equipment in storage, I tried to complete the current list and to prepare myself for the first visit.

At this visit, I took pictures of the equipment at storage, noted the relevant numbers and verified the list. With this information, I tried to verify the current value of the operating equipment.

The intention was to determine the impact that the maintenance history has on the current value of the equipment.

The inspiration for this question was a recent sale of airplanes at Lufthansa that was valued higher than the initial purchase price due to upgrades and meticulous maintenance performed on the aircraft during their lifetime.

Quickly after the start of the project I found that the maintenance history does have a factor in the residual value of operating equipment, but this was negligible compared to two other factors.

The first factor is that the operating equipment has to be adapted to the production facility of the purchasing party.

Unlike an aircraft, an asset in a production environment often operates in a chain. With the current developments in PLC and other monitoring software, the asset has to be adapted and updated to seamlessly fit in the new environment.

The costs of rebuilding and updating the asset to make them suitable for the new owner are higher than correcting any missed maintenance on the production equipment.

The second reason why maintenance is of lower priority is increasing developments in production equipment. Newer machines often have higher production capacities due to technological advancement. To remain competitive, most companies choose to purchase new, cutting-edge equipment rather than initiate the costly process of adjusting the previous technology to their production facility.

These two factors affect the value of the used operating equipment more than the maintenance history.

Despite abandoning the initial research question for my thesis, I continued this project by collecting data on the book value represented.

This greatly impacted any possible further actions, since assets representing book value cannot directly be sold due to the impact on the balance.

After working with the finance department, and cross-referencing the asset list of the finance department with the asset model numbers I found several assets that represented a combined book value of close to half a million euro’s. I also found that the asset list described several assets present in the warehouse that I couldn’t verify.

This lead me to track those assets down, and locating them in Asia after which those entries on the asset list were corrected.

1.1.2 Finding a second purpose for operating equipment.

With a complete list, the second step was to identify possible uses for the equipment within Unilever. This is preferable, not only because it avoids the necessity to purchase the equipment new, but also because of the competitive sensitive components in the equipment.

To this end, I managed to find a new destination for one of the assets, after a relatively cheap rebuild. The asset was a complete line for filling individual portion packs of margarine, and was disbanded due to the relative high conversion cost of those individual packs.

The conversion from the intended use as margarine portion pack to another product meant that studies had to be made to temperature and viscosity of the new product compared to margarine, but the results show that those values would be comparative to margarine and no drastic alterations had to be made.

However, there were quality issues at the repacker currently used due to temperature changes in transport. These problems would be resolved by using the available packaging line in-house.

Working with engineers and the previous maintenance crew of the line, I found that the initial investment needed to make the line operational would be recuperated in two years, after which the line would be profitable.

This lead to the problem of the high conversion costs. Even though the conversion costs were a lot lower than with the repacker currently used, they far exceeded the KPI on conversion costs of the factory. Therefore, I calculated the profit potential of the line, and suggested that the individual packaging line would be excluded from the calculation of the conversion KPI for the factory for the first years due to the low volumes of individual portion packs currently produced.

Eventually I achieved this by augmenting that the project would be experimental, and the new portion packs with improved quality would be a great promotion possibility for the product, with additional possibilities to use the line for other products as well.

1.1.3 Resale of equipment

The remaining assets represented no book value, and had no use in another part of Unilever. Therefore, it was decided to sell or scrap them.

After a market research was conducted on the second-hand market of production assets, three parties were contacted to make an offer on the equipment.

After they were invited to the warehouse for inspection, one party indicated that the production capacity of the equipment vastly exceeded the demand of the market they cater to, and withdrew from bidding.

The second party indicated that they too refused to evaluate the assets, and expected to be informed on the quotes other parties made. They would then make a ‘compelling counter offer’.

Due to this, they were excluded from the bid.

The third party quoted a number that was lower than the current market value of the raw materials.

This low quote, in combination with the risk of competitive information to be sold with the sale of operating equipment led to my recommendation of selling the remaining equipment to a scrapyard. After a few negotiations, I managed to receive an offer for more than the third party would pay. This offer also included collecting the asset ex works, and video proof of the destruction of the assets to ensure that no competitive information was lost.

1.1.4 Maintenance project

During the first project with stored operating equipment, I worked a lot with the maintenance department due to their knowledge of the assets.

When was decided that the first project wouldn't be a viable research option, I started looking for a new project with maintenance.

After a meeting with the maintenance manager, we decided that the best project would be to evaluate what was documented for maintenance at the central department. This was very well timed with a maintenance stop, and allowed me to closely observe the maintenance process at Unilever Nassaukade.

To use this project for my research assignment I evaluated the use of predictive, corrective, autonomous, and contract maintenance in the maintenance strategy. Since autonomous maintenance was very well implemented in the central department, this project gave me a very good look at the current situation and a good platform for my research.

After the project was done, I conducted a survey with two comparative Unilever BCS production sites to compare the findings at Unilever Nassaukade, and verify the results.

1.2 Literature study

This master dissertation will begin with an extensive literature study to gain insight in the roles and tasks of the maintenance department, as well as to gain knowledge on the concepts and theories within the field of maintenance. This knowledge will act as a solid foundation on which the dissertation will be built. To structure the literature study conducted in this paper, first the different types of maintenance policies are researched by comparative analysis. This method continuously compares, relates, and links identified categorizations, to continuously refine the concepts and categories.[3] For this study, the fundamental maintenance strategies of Corrective and Preventive maintenance were further developed with special interest in findings applicable to the case study which were further researched to develop a good fundamental knowledge upon which the case study can be conducted.

The results of the literature study will be discussed in chapter two and three. Chapter two acts as an introduction to maintenance, and covers the fundaments of maintenance and maintenance strategy. These concepts are used in this case study as a fundament on how to classify and manage maintenance. The second part of chapter two covers the organisation of maintenance. This part describes the importance of forming a schedule and maintenance strategy that is vital in the execution of this schedule. Chapter three covers the different third party maintenance possibilities that can be employed by a maintenance department to efficiently use their budget. An example to this type of maintenance outsourcing is to employ the services an Original Equipment Manufacturer (OEM), who has a better knowledge of the operating equipment, both by designing and building the equipment, and by having accumulated more data on the machines they produced and maintained for other companies. Additionally, these OEMs can demand an organization to employ their services on maintaining the equipment by refusing to supply details and spare parts of the equipment.

With the results of the literature study elaborated in chapters two and three a theoretical foundation is formed on which the case study can be built.

1.3 Interviews with maintenance personnel

Interviews with both maintenance engineers, and maintenance management are conducted to both estimate the current situation, getting a clear understanding on how maintenance tasks are

[3] Wolfswinkel, J. F., Furtmueller, E., & Wilderom, C. P. (2013), p51.

currently defined, and how they should be defined. These interviews will be held on location, and during this interview trips to the factory will be made to get a full understanding of the maintenance tasks that need to be defined and prioritized.

The purpose of qualitative interviews is described as "…to contribute to a body of knowledge that is conceptual and theoretical and is based on the meanings that life experiences hold for the interviewees."[4] Interviews can be categorized in unstructured, semi-structured, and structured, depending on how they are conducted. Depending on the structure, interviews can be classified as qualitative and quantitative, where structured interviews are better suited for qualitative data collection, and unstructured interviews result in qualitative data.

In an unstructured interview, the interviewer can ask questions openly, which can be freely discussed. It often starts with a broad, open question concerning the area of study, with subsequent questions depending on how the interviewee responds. It might seem that this type of data collection is not appropriate for the research question. However, by following a guideline comprising of themes rather than specific questions, the participant's thoughts and interests can be exploited in depth, which, in turn, generate rich data.[5]

When conducting a structured interview, participants are asked the same questions, in the same words and order. These interviews are done following a schedule that contains the set protocol of questions and 'probes', ensuring uniformity throughout the process.[6] This makes the structured interview a very efficient data-gathering method, with limited researcher bias. It is time efficient, both during the interview and during the transcription phase, however it allows little room for discovery of new information. This makes the structured interview a good method for researching large groups of people, but less efficient in investigating new ideas or unknown fields.

The semi-structured interview is most commonly used, where the researcher can freely ask questions, using predetermined questions as a guideline. This allows the researcher to follow up on new information, and ask further elaboration on previous statements.[7] This will also minimize the risk of misinterpretation. A downside of this type of interview is that it requires experience of the researcher to evaluate when to ask for a follow-up and when to move on to a new subject. Another negative characteristic to be considered is the possibility that the interviewer influences the interviewee, resulting the outcome of the interview.

This research will use the semi-structured interview model to investigate the current maintenance situation, and how maintenance functions are currently defined. Another point of interest will be the opinion of the maintenance employees on the current situation, and how they regard a possible new system. The interviews will be held at location of Unilever Nassaukade, both at an office, and at the factory to exemplify maintenance scenario's. This type of interview is defined as a semi-structured interview, since the topics will be known in advance to both the interviewer and the interviewee.

A preliminary interview was conducted to understand how maintenance is currently conducted and documented. This interview will be conducted on location at Unilever Nassaukade with the maintenance manager and a supply chain engineer. During this interview, the intent and scope of this dissertation will be discussed, and the agents most applicable for the interviews will be appointed.

[4] DiCicco-Bloom & Crabtree, 2006, p314.
[5] Doody & Noonan, 2013, p29.
[6] Doody & Noonan, 2013, p28.
[7] Doody & Noonan, 2013, p30.

1.4 Benchmarking and creation of a maintenance plan

Even though Benchmarking was originally intended as a problem solving technique (problem based benchmarking), leading organisations have found a better way to focus benchmarking activities and receive greater payback. Focussing on basic processes that run the organisation is the most effective vehicle to ensure continuous improvement. This (process based benchmarking) is a new and revolutionary perspective in benchmarking.[8] A characteristic of benchmarking is that it cannot be carried out in isolation. Benchmarking has to be aligned and contribute to the overall business objectives of the organisation to be of benefit.[9]

The limitations of benchmarking arise from the fact that it analyses the data, and not the processes that were used in creation of this data. Even though the shift from problem based benchmarking to process based benchmarking changes this, benchmarking should be regarded as an advisory tool, and not a definitive solution.

In the case break-down maintenance is required, an analysis of the current suppliers, ranked according to speed, accuracy, quality, and price will help to quickly respond to any delays in production with the optimal solution. This analysis will be used to develop a maintenance mix of break-down maintenance, preventive maintenance, autonomous maintenance and opportunity maintenance.

A further analysis of costs, strategic importance, and other benefits is then conducted to create a balanced maintenance system.

1.5 Reliability and validity

As this dissertation researches the maintenance in a single factory, it will be unlikely to repeat the study elsewhere with comparable results. As Gibbert et al.[10] state, the case study method has been prone to concerns regarding methodological rigor in terms of validity and reliability. Case studies are typically carried out in close interaction with practitioners, and they deal with real management situations. Case studies therefore represent a methodology that is ideally suited to creating managerially-relevant knowledge, however a rigor problem in the early stages of theory development would have ripple-effects throughout later stages when relationships between variables are elaborated and tested.[11]

Every description from a single user observer should be regarded as preliminary. Only when results are supported by numerous observers the description could be regarded as valid. One method of eliminating the tentative nature of a case study, a cross reference will be conducted, to be assured that the findings in one interview are consistent throughout the topic of study.

However, even with cross-verification, the findings of this study will be limited in terms of generalization. Findings might be contained to the scope of this study, and results may be impossible to replicate.

[8] Bhutta, K.S. & Huq, F., 1999, p254.
[9] Bhutta, K.S. & Huq, F., 1999, p255.
[10] Gibbert, M., Ruigrok, W., & Wicky, B. (2008), p1.
[11] Gibbert, M., Ruigrok, W., & Wicki, B. (2008), p1.

2. WHAT TYPES OF MAINTENANCE ARE AVAILABLE TO FORM A MAINTENANCE STRATEGY?

The present day maintenance manager has many strategies and tools to choose from when creating a maintenance strategy for the assets he is responsible for. Programs like TPM and WCM, often mandated from upper management, ask for a well thought-out maintenance strategy, with the available maintenance budget spent to ensure optimum availability of production equipment. In achieve this goal, a maintenance manager must choose what levels of service are assigned to different types of operating equipment to ensure optimum use of the available resources.

2.1 The role of maintenance has changed in the past century.

In the last century, the technological evolution in production equipment, an ongoing evolution that started in the twentieth century, has been tremendous. At the start of the twentieth century, installations were barely or not mechanized, had simple design, worked in stand-alone configurations and often had a considerable overcapacity. Not surprisingly, nowadays installations are highly automated and technologically very complex. Often these installations are integrated with production lines that are right-sized in capacity.[12]

The role of maintenance has been transformed from a production inevitability, to a strategic business function vital to accomplish business objectives.[13] The ongoing technical revolution in production equipment has inevitably affected maintenance. At the start of the twentieth century, installations were barely or not mechanized, had simple design, worked in stand-alone configurations, and often had considerable overcapacity. Installations not only became more complex, they also became more critical in terms of reliability and availability. Redundancy is only considered for very critical components. For example, a pump in a chemical process installation can be considered very critical in terms of safety hazards. Furthermore, equipment built-in characteristics such as modular design and standardization re considered in order to reduce downtime during corrective or preventive maintenance[14].

Redundancies worked in the design of operating equipment used to be commonplace, to accommodate an increased production life between breakdowns, since the machines were mainly maintained while they were repaired. The demands of production, and lack of a production line meant that downtime was usually not a critical issue, allowing maintenance to work on a breakdown basis. The rebuilding of the industry after the second world war, particularly the industries in Japan and Germany, developed a competitive marketplace, with downtime an unaffordable luxury.

The cost of labour became an increasingly higher amount of production cost, leading to higher and higher levels of mechanisation and automation. This required machines to be constructed with fewer and fewer redundancies built in, while running higher and higher speeds. Added to this, the 24 hour economy meant that the capacity of production equipment was utilized more fully. This inevitably meant that equipment became less reliable, and avoidance of production downtime demanded maintenance to prevent any equipment failures. Monitoring production equipment lead to the assumption that the older an asset became, the more likely it was to fail.

[12] Obrian, L.G. 1989, p3.
[13] Pintelon, L., & Parodi-Herz, A., 2008, p1.
[14] Obrian, L.G., 1989,p3.

This, combined with the failures occurring during the early phases of equipment, lead to the assumption of the “bathtub curve”[15].

The bathtub curve represents the idea that operation of a population of devices can be viewed as comprised of three distinctive periods; an early failure time (burn-in) period, a random failure time (useful life) period, and a wear out period, where failures occur increasingly frequent.[16] The advances in commercial aviation during the 1960’s, required improved reliability, and questioned current maintenance ideas. United Airlines used its database to develop age-reliability patterns for the non-structural components in their fleet, to investigate if equipment did follow the bathtub curve. They found that only a very small part of components (4%) actually followed the bathtub curve, but 89% of components never saw aging or wear out mechanisms developing during the useful life of airplanes.[17] Even though most production assets aren’t comparable with aircraft, the idea of monitoring equipment condition rather than assuming failure after a pre-set time born in this period still stands.

Introduction of terms like Total Productive Maintenance (TPM) and World Class Manufacturing (WCM) have revolutionised maintenance and changed the way maintenance is scheduled and conducted. Current market demand fluctuations, and the introduction of Just in Time (JIT) planning and Lean Manufacturing, it is increasingly important that production equipment is used as efficient as possible. To achieve maximum availability, proper maintenance planning is essential to reduce the adverse effects of breakdown and to maximize the facility availability to the equipment at minimum cost[18]. Traditionally, there are two major approaches when conducting maintenance.

Corrective maintenance reduces the impact of equipment failures as they occur[19], while preventive maintenance aims to reduce equipment downtime to a minimum. A combination of these types of maintenance is often used to keep production equipment in perfect operating condition. Finding the optimal mix of preventive maintenance and corrective maintenance to be both cost efficient and maximizing availability of production equipment is a challenging process, that requires detailed knowledge of the equipment. If machines are not properly maintained, they are more prone to failure, and might be down for large amounts of time, significantly disrupting production schedules. Results of this can significantly disrupt production output, and lead to missed market opportunities.[20]

Maintenance costs are a major part of the total operating cost of all manufacturing or production plants. The estimates on maintenance expenditure differ, and are often kept Depending on the specific industry, maintenance cost can represent between 15 and 60 percent of the cost of goods produced. These numbers can be misleading as they include modifications to existing production equipment driven by market-related factors, such as new products.[21] Nevertheless, maintenance accounts are substantial and represent a short-term improvement that can directly impact plant profitability.[22]

[15] Klutke, G. A., Kiessler, P. C., & Wortman, M. A. (2003), p1.
[16] Klutke, G. A., Kiessler, P. C., & Wortman, M. A. (2003), p1.
[17] Smith, A. M. (1993)., p3.
[18] Sheu & Krajewski, 1994, p1.
[19] Sheu & Krajewski, 1994, p2.
[20] Iravani & Duenyas, 2002, p423.
[21] Sheu & Krajewski, 1994, p1
[22] Mosley, 1990, p1.

2.2 Maintaining reliability of production assets

For most organisations it is now no longer a choice that they use opportunities that maintenance management offers to optimise their productivity, and maximize the Overall Equipment Effectiveness (OEE).

TPM which aims to organise all employees from top management to production line workers, is a company-wide equipment maintenance system that can support the most complex production facilities, while the ultimate objective of TPM is to keep both mechanical breakdowns and defects to zero.

Reliability centred maintenance focusses directly towards machine and plant assets. Reliability-centred maintenance is a process used to determine the maintenance requirements of any asset in its operating context, and to what must be done to ensure that it continues to fulfil its intended function.[23] While the focus of TPM lays company-wide, at RCM the focus is more directed towards technology and offers a sound basis for assessing maintenance requirements in this context.

Since RCM was developed by, and for, the USA commercial airline industry, the changes to maintenance management defined by RCM have evolved. These changes cumulated in a maintenance programme that focusses preventive maintenance on specific failure models likely to occur for any physical asset. RCM also places great emphasis on the need to quantify performance standards where possible. These standards cover output, product quality, customer service, environmental issues, operating costs and safety.[24]

While time consuming, the RCM review yields four principal outcomes:[25]

The first principle is a greatly enhanced understanding of how the asset works, with a clear understanding of what it can and cannot achieve.

The second principle is a better understanding of how the asset can fail together with the root causes of each failure. This helps to optimally use the maintenance resources. It also helps people to understand why things might fail, which leads to them stop doing those activities.

The third principle is to have lists of proposed tasks designed to ensure that the asset continues to operate at the desired level of performance. This lists take three forms;

Maintenance schedules to be done by the maintenance department

Revised operating procedures for the operators of the assets

And a list of areas where changes (usually design changes) must be made to deal with situations where maintenance cannot help the asset do deliver the desired performance in its current configuration.

The fourth and last principle is greatly improved team working.

When these four principles are implemented, the understanding of how an asset works, and more importantly, how an asset can fail, is greatly improved.

Through this insight, RCM helps the understanding in the weaknesses and failure points of the operating assets.

2.3 Maintenance strategy and policy

Containments on resources for maintenance, like budget or time, often force maintenance managers to identify key maintenance activities to optimise the use of the available resources.

[23] Mostafa, 2004 p1.
[24] Fraser, K., Hvolby, H. H., & Watanabe, C., 2011, p294.
[25] Moubray, 1991, as listed by Fraser, K. Hvolby et al. 2011, p294.

This knowledge of key maintenance activities can then be applied to form a maintenance strategy. Maintenance strategy aims to find trade-offs between maintenance expenditure and system risks and/or profits.[26]

There are a number of reasons why there is a lack of commitment of managers to maintenance models. The most obvious reason is that managers are often unaware of the various types of maintenance models. The second reason is a lack of full understanding of models, and why these systems are appropriate to the company. A third reason is that the complexity of mathematical models, mostly due to their unrealistic assumptions, results in a lack of confidence by management.[27]

Most maintenance departments have a limited budget. A maintenance strategy ensures that the limited resources are optimally employed to ensure equipment continuity and reliability.

Another important consideration is the type of maintenance required throughout the organisation. A lightbulb in the office will not require preventive maintenance, but can be replaced when it breaks. Lights in traffic lights should be replaced timely to prevent a uncontrolled intersection. A light in a photo development studio should be monitored carefully, since malfunction of the bulb can immediately ruin the entire project.

Maintenance costs fall into two major categories; PM cost for the elements selected for this type of maintenance and CM for when failures occur.[28] Even with the best preventive maintenance, there will be inevitable breakdowns. These may be caused by human error, faulty specifications, or undetected problems with equipment. These irregularities result in a difficulty for the budgeting of maintenance.

Life Cycle Management, and Life Cycle Costing (WCC) will contribute to a realistic approach of maintenance policy, including decision making, planning, budgeting, and funding of inspection and repair activities.[29] During the lifetime of an asset, maintenance costs for the asset can quickly accumulate to more than the original purchase price. If for example, investing ten percent of the assets value per year can double the assets workable life, the investment is well worth consideration. Kaufman has developed an eight step approach to Life Cycle Costing.

By accounting for operating profile, utilization factors, identifying all cost elements, determine critical cost parameters, calculate all costs at current prices, estimating costs at assumed inflation rates, discount all costs on the base period, and sum those costs to the net present value, an accurate cost of the asset can be calculated.[30] This cost can then be compared with the costs of other assets. This comparison can be used to choose the best asset to purchase, but also allows for fitting the new asset in a maintenance strategy, by estimating what maintenance should be conducted and at what time in the assets life. By planning costs incurring during the lifetime of an asset, like changing of consumable parts, or updating the machine to a new system standard, maintenance costs can be more accurately planned, and the need for CM will be reduced.

2.4 Types of maintenance management

At the beginning of the 19th century, the operators of equipment were also responsible for its maintenance. This maintenance usually meant fixing the equipment when was broken. The machines had a lot of redundancy in them, with some of them operational to this day.

[26] Liu, Y., & Huang, H. Z. (2010), p357.
[27] Shorrocks & Labib, 2000, p3.
[28] Liu, Y., & Huang, H.Z. (2010), p361.
[29] Zen, K., 2005, p2358.
[30] Kaufman, R.J., 1970, p1.

Maintenance has come a long way since then. The high costs associated with maintenance has attracted the attention of management who regarded maintenance as a necessary cost. Later, the results of Total Preventive Maintenance (TPM) applied at Toyota have shown that maintenance can be a strategic part of business. Today, maintenance managers can choose from different strategies to ensure continuous operation of production equipment. For equipment which breakdown has a low impact on production, it may be wise to run them until they fail, at which point they can be repaired or replaced.

When production equipment is crucial for continuous operation, a strategy to repair or replace parts before they fail

For equipment whose failure will directly affect production, more attention may be required. Repairing or replacing parts prone to failure to prevent the breakdown allows for the maintenance stop to be scheduled at a more convenient time.

To optimize preventive maintenance strategies, the condition of crucial components as gears and belts can be monitored with the use of several techniques. Using techniques as thermal imaging, vibration analysis, or audio analysis allows engineers to replace or repair parts at the optimal time, while still preventing breakdowns. This practice of Condition Based Maintenance (CBM) increases the usable life of components, thus reducing maintenance costs.

Some organisations choose to outsource some of its maintenance, or all of it. A survey of the Plant Maintenance Resource Centre conducted in 2001 showed that the main reasons to choose for outsourcing maintenance were allowing maintenance engineers to focus on ‘core’ activities, reduce maintenance costs, increase labour productivity, and obtaining skills that are not available in-house.[31]

Routine maintenance activities as (visual) inspections, cleaning, lubricating, and tightening of bolts can be conducted by the operator working on the equipment. This does not only free up time for maintenance engineers to focus on preventive maintenance activities, but additionally creates a larger sense of responsibility for the operator. This type of maintenance is called Autonomous Maintenance (AM), and is a vital part of TPM and World Class Maintenance (WCM).

2.4.1 Allowing equipment to break down before maintaining or replacing them.

Corrective maintenance (CM), also known as breakdown maintenance[32], or run-to-failure maintenance is performed when a production machine encounters a problem that disrupts operation.[33] It can be used when the failure of the equipment does not significantly affect production or generate a significant loss other than repair cost.[34] Corrective maintenance is carried out after failure of the equipment, and restores equipment to working order. Corrective maintenance requires replacement parts to be ordered at the last minute, or spares to be kept in inventory, both expensive options. It also means that production is halted, since the time of failure will occur during production. The lost production time brings the added cost of idle production staff for the duration of the repair. All considered, corrective maintenance. The reactive nature of this strategy makes corrective maintenance the most expensive method of maintenance management. For this reason, the aim of most maintenance strategies is to keep corrective maintenance to a minimum by employing preventive maintenance strategies.

[31] Plant Maintenance Resource Center, 2001, p3.
[32] Venkatesh, 2007, p2.
[33] Mosley, 1990, p2.
[34] Venkatesh, 2007, p2.

2.4.2 Using preventive maintenance to avoid equipment failures, and ensuring production capacity availability.

Maintenance aims to reduce equipment downtime to a minimum. To achieve this, a machine is maintained to a certain point, either like-new status (zero-life), or a pre-determined service level. There are several strategies to keep equipment at a certain condition. Age dependent Preventive Maintenance is the most common and popular maintenance policy. Under this policy, an unit is always replaced at a certain age or failure, whichever occurs first.[35] Under the Periodic Preventive Maintenance policy (PPM), an unit is preventively maintained at fixed time intervals independent of the failure history of the unit, and repaired at prearranged times.[36] Early scholars on PPM assume that a machine is in an as good as new condition after maintenance.[37] However, a more realistic assumption is that Preventive Maintenance is that the system is left in a state somewhere between as good as new, and as bad as old.[38] The state in which Periodic Maintenance leaves the system depends on the strategy of the firm. An imperfect maintenance policy, where calculated risks are taken in favor of lower maintenance costs, can be implemented when a machine is replaced after a set time.[39]

Under the Failure Limit policy, preventive maintenance is performed only when the failure rate or other reliability indices of a unit reach a predetermined level and intervening failures are corrected by minimal repair.[40] Under this policy, there is a distinction between preventive maintenance (maintenance type 1P), and replacement maintenance (maintenance type 2P), and the degree of improvement in failure rate after 1P is called the improvement factor. A set of curves for the improvement factor as a function of cost for maintenance type 1P and age of the system is proposed. The cost rate for a system is formulated as a ratio of an average cost for a cycle (time between replacements) to an average cycle length. An optimum number of type 1P maintenance actions before type 2P maintenance is obtained by minimizing the cost rate when the failure times are Weibull distributed. The optimum solutions are a function of improvement factors and predetermined upper limit of failure rate.[41]

Unlike the PPM policy, a unit is preventively maintained at unequal time intervals under the sequential preventive maintenance policy. Under this sequential policy, the age for which preventive maintenance is scheduled is no longer the same following successive preventive maintenances, but depends on the time still remaining. The next preventive maintenance interval is selected to minimize the expected expenditure during the remaining time.[42]

Barlow and Hunter studied two preventive maintenance policies.[43] Under Policy I, preventive maintenance both repair and replacement is done after a set time frame, or when the system fails. When maintenance has taken place, the time until maintenance is planned is reset. This can be done with less complex equipment. Policy II is used in more complex systems. In these complex systems, it is assumed that different components are unaffected by the repair, and therefore maintenance is planned after a predetermined number of operating hours, regardless of the number of failures.[44] Makabe and Morimura expand on these policies by adding a third policy. Under Policy III, a minimal repair is done for the first predetermined number (*k-1*) of failures of the system, and completely overhauled after (*k*) number of failures.

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35 Sarkar et al. 2011, p131.
36 Sarkar et al. 2011, p132.
37 Barlow & Hunter, 1960, p90, Bowland & Proschan, 1982, p1183.
38 Jack & Dugnapar, 1993, p1.
39 Jack & Dugnapar, 1993, p5.
40 Sarkar et al., 2011, p133.
41 Lie & Chun, 1986, p787.
42 Sarkar et al., 2011, p135.
43 Barlow & Hunter, 1960, p1.
44 Barlow & Hunter, 1960, p1.

Cost based maintenance strategies take repair cost into account, and replace the unit after a predetermined repair cost limit is reached.[45] This prevents the situation where a faulty system is maintained at very high costs, while replacement would have been more cost-efficient

2.4.3 Integrating preventive maintenance in the production schedule.

When Nippondenso first implemented Total Preventive Maintenance, maintenance of equipment required more maintenance personnel. The managers decided that maintenance could be executed by the operators of the machine. This practice is called autonomous maintenance, and is one of the eight pillars of Total Productive Maintenance.[46] Total Productive Maintenance originated as a Japanese school of thought initiated by Siiechi Nakajima.[47]

There are two main approaches to defining TPM, a Western Approach, and a Japanese Approach.[48] Siiechi Nakajima is the vice chairman of the Japanese Institute of Plant Maintenance, and promotes the Japanese Approach. Nakajima's Japanese definition of Total Productive Maintenance is characterized by five key elements; First TPM aims to maximize equipment effectiveness, Secondly, TPM establishes a thorough system of Preventive Maintenance (PM) for the equipment's life span. Thirdly TPM is cross-functional and implemented by various departments, like engineering, operators, maintenance, and managers. Fourth, TPM involves every employee. And lastly, TPM is based on the promotion of Preventive Maintenance through the motivation of management and autonomous Small Group Activity (SGA).[49]

The Western Approach differs from the Japanese Approach by approaching TPM first from equipment improvement objectives while understanding that operator involvement and participation in TPM is required, rather than emphasizing the participation of all employees are needed in the TPM process to accomplish equipment improvement objectives.[50]

The ability to produce efficiently depends production as well as maintenance employees, but in reality, the relationship between operators and maintenance personnel is often adversarial. Even with the maintenance department trying their utmost in keeping equipment operational, they can do little in maintenance and equipment improvement as long as the operator's attitude towards maintenance is "I operate – you fix".[51]

A vital part of TPM is autonomous maintenance. Through autonomous maintenance, operators learn to carry out important daily tasks that maintenance people rarely have time to perform. These tasks include cleaning and inspecting, lubrication, precision checks, and other light maintenance tasks. With these tasks transferred to operators, maintenance people can focus on developing and implementing other proactive maintenance plans.[52] Another benefit of autonomous maintenance is the knowledge the operators have over the equipment they work with. They learn what common problems may occur, why, and how to prevent these problems through early detection and treatment of abnormal conditions. This cross-training allows operators to maintain equipment and to identify and resolve many basic equipment problems.[53]

[45] Drinkwater & Hastings, 1967, p1.
[46] Venkatesh, 2007, p3.
[47] Nakajima, 1988, p1.
[48] Pomorski, 2004, p3.
[49] Pomorski, 2004, p3.
[50] Pomorski, 2004, p4.
[51] Yamashina, H. (1995), p10.
[52] McKone, Schroeder & Cua, 1999, p125.
[53] McKone, Schroeder & Cua, 1999, p126.

Lean Manufacutring, or the Toyota way, is a systematic method aiming to eliminate waste, or "Muda", within a production process. This is achieved through

Yang et al. describe Lean Manufacturing as "A set of practices focused on reduction of waste and non-value added activities from a firm's manufacturing operations".[54] Essentially, lean manufacturing is a set of practices that highlights what adds value by reducing everything that does not add value. This practice was first developed in Japan after materials, labour, and money were scarce after the second world war. By employing Lean Manufacturing, an organization implements a distinct bundle of organisational practices. Practices include JIT, Total Quality Management (TQM), Total Preventive Maintenance (TPM), and Human Resource Management. When employed together, they allow an organization with less waste and lower stock levels.

Traditionally, the Greek letter Sigma, σ, is used by statisticians to measure the variability in a process. This can be used to measure the performance of a business in levels of variability, or Sigma Levels. Traditionally, companies with three or four Sigma levels were accepted as normal performers, even though they had between 6,200 and 67,000 problems for every million opportunities. By employing Six Sigma, companies try to face only 3.4 problems per million opportunities[55] Six Sigma is not a new mathematical method, but rather a combination of proven methods and train a small number of in-house technical leaders known as Black Belts to a high level of proficiency in the application of these methods. The tools used by Six Sigma are applied within a performance improvement model known as Define-Measure-Analyse-Improve-Control, or DMAIC. The steps in DMAIC are to Define the goals of the improvement activity, Measure the existing system, Analyse the system to identify ways to eliminate the gap between the current performance of the system or process and the desired goal, Improve aims to improve the system, and the final step is to Control the system.[56]

2.4.4 Optimal replacement time

In some cases, replacing a component might make more economical sense than keep maintaining it. However, determining when to replace a component is difficult and often uncertain.

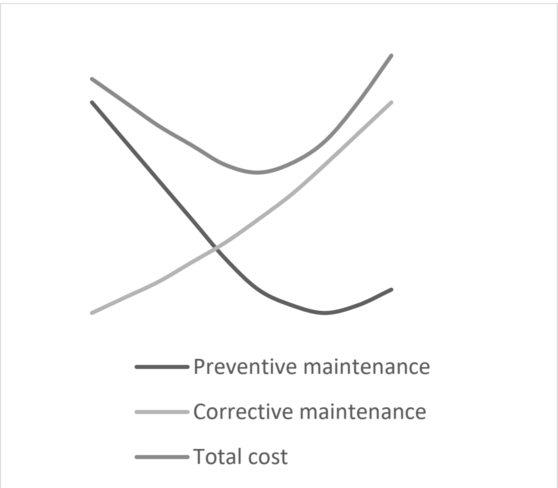

Figure 1 Optimal Replacement Cost

[54] Yang, M. G. M., Hong, P., & Modi, S. B. (2011), p252.
[55] Pyzdek & Keller, 2014, p23.
[56] Pyzdek & Keller, 2014, p24.

Preventive replacement of components is only acceptable if the component are more likely to fail over time, and if the cost of replacement is significantly less than the cost would be if the replacement would be if it were done after the component broke down.

If both conditions are met, the optimal point of replacement can be calculated by plotting the cost per operating time against the operating time. The optimal point is then when the risk of breaking down exceeds the cost of unnecessarily replacing the component. By calculating the intersection between preventive maintenance cost per operating time against the corrective maintenance cost, the optimal replacement cost can be calculated.

2.4.5 World Class Manufacturing

Zero optimum (zero accidents, zero stock (lean), zero defects (six sigma))

"World Class Manufacturing (WCM) has an overriding goal and an underlying mind set for achieving it."[57] The overriding goal is defined by *continual and rapid improvement*. These continual improvements can be made in areas like cost, lead time, and customer satisfaction. World Class Manufacturing combines the school of Total Preventive Maintenance with Six Sigma and Lean Manufacturing. The ten pillars of WCM are all represented with a manager within the organization. This forces extra attention on the areas the pillars represent, and allows for little improvements, or kaizens, in each of these pillars.

Recent development in equipment condition testing allows for accurate testing of the current state of the equipment. This allows maintenance engineers to better anticipate upcoming failures and schedule the needed maintenance before the failure occurs. Another benefit of accurate condition testing is that parts can be used for longer before they have to be replaced, lowering maintenance costs, without increasing risk of equipment failure during production. Conventional condition-based maintenance (CBM) reduces the uncertainty of maintenance according to the needs indicated by the condition of the equipment.[58] Condition-based maintenance can be supplemented with an intelligent predictive decision support system (IPDSS) by adding the capability of intelligent condition-based fault diagnosis and the power of predicting the trend of equipment deterioration. These systems can increase the dependability and allow maintenance managers to further increase the efficiency of maintenance.

Visual inspection is usually defined as an inspection, where the supervisor makes use of one or more of the human senses e.g. eye sight, hearing, and taste.[59] The supervisor might make further use of other tools like hammers or magnifying glasses to further inspect the equipment. Visual inspection is often autotomized and executed by an operator of the equipment at fixed times

The vibrations of linear systems fall into two categories – free and forced. Free vibrations occur when a system vibrates in the absence of any externally applied forces (i.e. the externally applied force is removed and the system vibrates under the action of internal forces). A finite system undergoing free vibrations will vibrate in one or more of a series of specific patterns. These specific vibrations patterns are called a mode shapes, and vibrate at a constant frequency, called a natural frequency. These natural frequencies are properties of the finite system itself and are related to its mass and stiffness (inertia and elasticity). Forced vibrations, on the other hand, take place under the excitation of external forces. These excitation forces may be classified as (i) harmonic, (ii) periodic, (iii) non-periodic (pulse or transient), or (iv) stochastic (random). Forced vibrations occur at the excitation frequencies, and it is important to note that these frequencies are arbitrary and therefore independent of the natural frequencies of the system. The phenomenon of resonance is encountered when a natural frequency of the system

[57] Schonberger, R. J. (2008), p2.
[58] Yi et al., 2001, p1.
[59] Rytter, 1993, p15.

coincides with one of the exiting frequencies.[60] These natural vibrations can be used to detect wear or defects by detecting unbalanced parts, misalignment, looseness, or other defects.

The response of the structure will typically be measured by means of accelerometers and/or strain gauges. A local defect somewhere in a structure will in principle lead to a change in the overall dynamic characteristics of the structure. This means that he sensors can be placed anywhere in the structure away from the defect, which of course makes this method very attractive. However, this form of global measurement is only applicable to detection of defects of a certain magnitude, since small defects will have no significant influence over the overall dynamic parameters.[61]

Other than condition-based maintenance, predictive maintenance uses the acquired controlled parameters data to analyse and find a possible trend. This trend is then used to predict when a predetermined threshold value will be reached. This will help the maintenance department to plan when it is the best time (or unavoidable) to replace or maintain a part, and schedule this in relation to the production schedule or combine it with other maintenance tasks.[62]

2.5 Organizing maintenance

Manufacturing facilities are often complex operations with many interrelated components. If one component fails, it can directly affect other components in the system, either by disruption of continuity or by placing the equipment under additional stress and load. Group maintenance focusses on replacement or repair on a group of machines when a failure occurs. An optimal estimation of service levels for assets can greatly improve the use of the resources allocated for maintenance. On the other hand, user requirement like updating of equipment to latest standards, or to accommodate new production, and the unpredictability of unforeseen break-downs require maintenance schedules to be flexible. To accommodate for this flexibility, a mix in maintenance policies is used when making a schedule. To optimize the use of this schedule, there are a few factors that should be considered in the planning phase. First, the maintenance tasks are prioritised, then the type of maintenance per task is considered, And lastly costs evaluations are made.

Preventive maintenance can be planned in advanced to fit in the production schedule, and therefore create minimum downtime during production. If maintenance tasks are well defined in terms of priority and dependencies, unexpected opportunities for maintenance can be utilized. This is especially true for series systems, where a single failure results in a systems downtime. Components that haven't failed, and are in good condition shouldn't be replaced, because then the useful lifetime is wasted.[63] One of these opportunities is maintenance under group maintenance policies, but other opportunities are a transient accumulation of parts in a buffer downstream from a degraded machine.[64] In order to calculate the opportunity window in which a machine is assumed down, the upstream and downstream processes may still continue for a short time, permitted by the buffer of the work in process (WIP). This time period, together with the effect of other failed machines determine the impact on production of taking a machine down for repair.

When scheduling maintenance, it is important to make a distinction in the priority of the maintenance tasks that need to be conducted. The classification in terms of priority determines the order in which maintenance tasks are carried out. This is important, not only in terms of risk

[60] Norton & Karzcub, 2003, p3.
[61] Rytter, 1993, p16.
[62] Bevilacqua & Braglia, 2000, p73.
[63] Nicolai & Dekker, 2008, p10.
[64] Chang, Ni, & Bandyopadyay, 2007, p1.

of failure, but also when planning maintenance around production. Some lower priority tasks may be scheduled during opportunities for maintenance that arise during production, while high priority tasks can require a pre-planned production stop of production. When a pre-determined priority classification is developed, a maintenance department can plan the time allotted for maintenance in accordance to tasks that have high priority, and can quickly determine what tasks are best done when an opportunity for maintenance presents itself.

In the Analytic Hierarchy Process relationships among decision factors are considered rather than the factors individually. A relation matrix built around the relative preference of one candidate over another is used to derive weights, which are used to characterise these relations. This process also quantitatively represents all work-order character values on their value preference over each other, which can be both objective and subjective. The final priority value for each work-order is the summation of candidate character values multiplied by their associated weights.[65] These priorities are then used to determine the order in which the maintenance tasks are executed, and which tasks to execute first when an opportunity for maintenance occurs. It should be noted that these found priories can change, since the importance of machines in a highly dynamic system may change over time.[66]

As with most organizational activities, computers have drastically changed the effectiveness and efficiency of maintenance. The combined spending on information systems and Information Technology within an organization can now command a considerable amount of the budget, averaging between 1 and 4 percent. The impact of IT on maintenance management is still relatively young in the business tools arena. Additionally, maintenance management requires high levels of interaction with other business functions as enterprise-wide information management and business planning becomes the norm rather than the exception.[67]
Computerized Maintenance Management Systems exist for several decades, and evolved from a simple planning tool to a full multi-user package covering a multitude of maintenance functions.[68] Some of the functionality of a CMMS includes equipment management and control, plant management and control, predictive maintenance procedures, drawing and document management and control, planned and unplanned maintenance management, work order management, resource management, historical data analysis, cost and budgeting control, inventory management, and purchasing order management.[69]

Not all of these functions are exploited fully by businesses, as CMMSs are usually considered a black hole, a system greedy for input but rarely offering output in the forms of decision support. At most, it is used as a diary to schedule maintenance and checked when maintenance was last conducted.[70] While great advantages can be achieved by implementing CMMS systems, there are pitfalls to be wary off. Sullivan et al. mention the four major points a CMMS system can fall on; First, there is the improper selection of the CMMS vendor. The wrong software impacts communication with existing software, complicating the situation. The second pitfall is inadequate training of Operations and Maintenance administrative staff on proper use of the system. Staff needs dedicated training on input, function, and maintenance of the CMMS. Thirdly, there needs to be commitment to properly implement the CMMS. The system can only function well with complete data implemented and full system implementation throughout the factory. Gaps in data can lead to oversights or suboptimal decisions. Lastly, there needs to be

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[65] Yang et al., 2007, p435.
[66] Yang et al., 2007, p436.
[67] Uysal & Tonsun, 2012, p213.
[68] Labib, 2004, p2.
[69] Uysal & Tonsun, 2012, p214.
[70] Labib, 2004, p2

commitment to persist in CMMS use and integration. It is recommended that there is a "champion" that ushers and encourages its continued use.[71]

Downtime opportunities can be utilized to conduct maintenance. This way the system downtime results in cost savings since more components can be replaced at the same time. Moreover, by grouping corrective and preventive maintenance the downtime can be regulated and in some cases it can even be reduced.[72] A downside to this system is that it cannot be accurately planned, and requires more manpower when the machine is down. This results in excess maintenance engineers during uptime of equipment, which could lead to higher expenses than the cost saved with combined maintenance. A solution for this problem might be assigning priorities on maintenance tasks. This way, when an opportunity arises, the tasks with the highest priority can be executed first, while lower priority maintenance tasks can be scheduled for a later time.

An important question when planning maintenance is how often to perform preventive maintenance. Performing more preventive maintenance will result in lower failures, but higher costs are involved. Balancing the cost of failure with the cost of maintenance results in the optimal maintenance time. Preventive maintenance or replacement of a component is conducted as the component's vulnerability to failure increases over time, and when the preventive replacement cost is less than the cost associated with component failure.

If these requirements are met, the Optimal Replacement time can be found by minimizing the sum of the preventive replacement cost and the component failure cost.

In reality, the cost of failure is calculated with parameters associated with component failure. These parameters include replacement cost, loss of revenue, cost of downtime,

[71] Sullivan, G. P., Pugh, R., Melendez, A. P., & Hunt, W. D. (2004), p29.

[72] Nicolai & Dekker, 2008, p7.

2.6 When is it beneficial to buy maintenance from a second party, and when to conduct maintenance in-house?

The rapid pace in which the competitive environment of production companies moves, ensures that they are always searching for new methods and strategies to increase their competitive advantage. Outsourcing of maintenance can be one of the strategies used to gain this competitive advantage by employing the expertise and knowledge of equipment from another party, without the need of in-house knowledge development of ever changing equipment. An early form of outsourced maintenance was the ‘power by the hour’ program by Rolls Royce engines. The Power by the Hour contract “implies that the engine operator will buy a fleet of engines, but no spares. The engine manufacturer then agrees to supply spare engines, accessories or modules when required, and to perform all the maintenance work required on the fleet of engines. The rate paid by the customer is charged per flying hour, and the manufacturer would then be required to carry out all the required maintenance of these engines.”[73] In this type of contract, much of the technical risk is carried by the manufacturer, and the operator of the aircraft can focus on the core business. The manufacturer can accurately estimate the life cycle cost of these engines, and use the experience gained by increasing efficiency.

Outsourcing maintenance can also have some downsides that must be taken into account. Losing control of the assets the maintenance also leads to a loss of knowledge and control about the asset.[74] An organization can’t change the asset in fear of losing guarantee, and is therefore forced to buy upgrades from the manufacturer instead of applying them in-house at lower cost.

Another risk to be considered is a possible dependency on the supplier. A supplier is not always on-site when an asset fails. This leads to higher failure costs, as well as a larger loss of production.

There must also be incentives for the contractor to maximise effectiveness and achieve the optimum lowest unit cost for the client.[75] The contract needs to be balanced to avoid the client to overpay for maintenance, while guaranteeing the contractor maintains the equipment to a high standard.

The introduction of autonomous maintenance also blurs the line between operating and maintaining the equipment, while for outsourcing the maintenance this line should be carefully defined to prevent cross overs, and possible breaches of contract.

Lastly, the performance of the contractor should be benchmarked, to allow for evaluation of the contract.

2.7 Hiring external parties to conduct maintenance tasks.

A small survey of Plant Maintenance conducted in 2001 found that the most commonly heard reasons for outsourcing maintenance was to increase labour productivity, reduce maintenance costs, focus in-house personnel on core activities, reduce management effort, obtain specialist skills not available in-house, level fluctuations in the workload, and improve equipment uptime/performance.[76]

By outsourcing non-essential maintenance tasks, the maintenance department can focus on the operating equipment that is essential to ensure production availability. This way the available maintenance personnel specialize their skills, and execute them more efficiently, while the

[73] Bagnall, Shall, & Mason Flucke, 2000, p2.
[74] Bertolini, et al. (2004), p774.
[75] Levery, 1998, p6.
[76] Plant Maintenance, 2001, p3.

routine maintenance tasks are performed by off-site specialized companies who can do those tasks more efficiently.

This mix of in-house and outsourced maintenance also allows for a more continuous maintenance department occupation, and the use of extra expertise and help when needed. This method requires fewer maintenance personnel, resulting in lower maintenance costs.

Another vital reason for outsourcing maintenance is that it is either too expensive, or not possible to have the knowledge and capability needed for maintaining equipment in house. For the case of Rolls Royce, a single airline would either require inventory of spare parts over the entire world to maintain engines, or require aircraft to fly to a specific airport for maintenance and purchase maintenance locally at very high costs. The use of the maintenance programme offered by Rolls Royce allows airlines to lower these safety stocks of parts, while keeping the same level of dependency. Rolls Royce can use a single warehouse of parts and mechanics to work on planes operated by different airlines allowing for lower costs both for Rolls Royce, and for the airlines.

There is a lot of knowledge on operating equipment lost when maintenance of that equipment is outsourced. Therefore the operations to be outsourced should not be a part of the core strategy or core competence of the firm. There is a risk that core competences, and production methods that give a competitive edge will be copied by the contractor and sold to competitors. Therefore, the choice of what equipment to maintain by in-house expertise and what equipment to maintain by the use of external contractors is of high strategical importance.

2.7.1 Outsourcing maintenance for non-strategical repetitive maintenance.

Generally speaking, standardised, well-defined, and repetitive maintenance tasks such as the maintenance of power tools, or forklift trucks are good candidates for outsourcing.[77] They are of no strategic importance to the firm, and there are often many parties available who are specialized in the execution of this equipment. However, if the choice is made to employ the services of a contractor to fulfil specific maintenance needs, the partner with the minimal risks and maximum performance must be selected.

To evaluate which contractor is the best possible partners, the candidates should be selected on, for example, geological position, perceived quality, contractor flexibility technical excellence, plant know-how, and low price.[78]

Before the outsourcing of maintenance is considered, the current performance of maintenance should be understood in terms of quality, quantity, cost, and effectiveness. This will allow for a benchmark to which a future contractor can be measured.[79] However, this might not always be possible, for example when the contract is accompanied by the acquisition of new production equipment, or when the maintenance contract concerns equipment that can only be maintained by the manufacturer. A possibility to accurately measure the performance of outsourced maintenance is measuring the number of failures, the amount of usable time between maintenance and the tested condition of an unit. A problem with these parameters is that it will fail to detect the scenario where maintenance policies of the contractor, for example under threat of high fines in case of production failure or to increase its profits, result in unnecessarily high maintenance costs that could otherwise be avoided. For example, when an office has a contract for its printer, but if the contractor decides to change the cartridge when its half full to avoid ink shortages, the associated costs will be unnecessarily high, but when just the number of

[77] Bertolini, et al. 2004, p775.
[78] Bertolini, et al. 2004, p776
[79] Levery, 1998, p6.

failures is measured, and no previous knowledge on how much ink is used, no abnormalities will be found.

A possible solution to this problem is to record data on the maintenance. This historical data on maintenance frequency, response times, spare parts on stock versus usage of spare parts, and failures can then be used to evaluate the current performance of the contractor. In some branches, maintenance costs or indices are published, and can be checked against performance of the firm.

2.8 Maintenance contracts with OEM suppliers

Organisations who originally manufactured a piece of equipment, usually possess the knowledge of the engineering design, technical skill, know-how and tools required to manufacture that product. These assets can also be used in maintain the equipment. The use of these OEM (Original Equipment Manufacturer) maintenance programmes can be very attractive given the experience and equipment these OEMs have over the equipment. It can, however, be wise in some circumstances to maintain equipment in-house, especially if equipment is of high strategic importance to the organisation. Another problem with OEM maintenance programs is availability. During the writing of this dissertation, a machine broke down halting an entire production line. The OEM did have spare parts, but they were at least a week away. For this reason, the decision was made to have the part custom made locally, trading experience and cost for a shorter production stop.

Use of this maintenance program sometimes is not optional. In some cases, the owner has no choice but to choose for this program given essential information such as construction manuals or information about spare parts is not provided by the OEM.[80] These practices often result in a lack of competition, and therefore a profitable business for the OEM. This has to be considered at the time the decision to purchase the product is made.

2.9 Engineers in a maintenance department maintain the assets

The increase of mechanization and automatization in production facilities has reduced the number of production personnel, while increasing the capital employed in production equipment. As a result, the proportion of employees working in the maintenance area compared to the production personnel has grown, as well as the fraction of maintenance spending on the total operational cost.[81] This has resulted in an increased attention on the maintenance department by management, who regards maintenance as a necessary cost, and would prefer to reduce this significant cost (sometimes as high as 20% of total cost) as much as possible.

Simultaneously, maintenance has become more complex due to higher levels of automation and increasing production speeds. Maintenance employees needed a broader set of skills to cope with complex equipment. The choice whether a maintenance crew should possess specialized skill groups or a multi-skilled maintenance crew is an important debate. The size of the maintenance crew should also be carefully determined, especially in environments where hiring and firing is not easy.[82]

Managers of maintenance departments are seeing a shift in the skills that workers need. The need for general skills as electrician, welding, or specialization in hydraulics is decreasing, with increasing demand for new skills like solid state electronics specialist, or workers specially

[80] Martin, 1995, p9.
[81] Dekker, 1996, p229
[82] Dekker, 1996, p310.

trained by equipment manufactures. The skills represented in an effective maintenance labour pool are increasing in sophistication with the changes in production technology. These developments have great impact in the areas of staffing and training, and the available skill within the maintenance department needs to be managed. Knowledge on what skills are needed and what proportions of skills are appropriate for the labour pool can be expected to become crucial in the near future.[83]

Maintenance engineers who are employed within the organization possess in-depth knowledge on the equipment, operations, and projects in the factory. The working relationship that the maintenance engineers have with the operators of the equipment allows for a better alignment between the two departments. This alignment results in a more efficient

There are several reasons to choose for in-house maintenance rather than outsourcing maintenance; Firstly, maintenance must be closely linked to production. This link is weakened with outsourcing.

Secondly, there might be a discrepancy between the long-term goals of the service agent and the business may be different. Since maintenance contracts are often relatively short-term compared to the lifespan of the equipment, the maintenance conducted by the service agent might not align with the long-term needs of the business.

A third concern is the knowledge associated with maintenance. The service agent learns a lot about the specific equipment while maintaining it. This knowledge is lost when the business switches to another service agent. The high costs associated with this switch result in a dependency on the service agent. This dependency is disadvantageous for the business during contract negotiations, and creates additional risks of potential bankruptcy of the service provider, or discontinuation of the service contract.[84]

Finally, the service agent might use the knowledge acquired at the business of the principal, and apply it elsewhere, potentially losing the competitive edge created by the principal.

The downside of maintaining an in-house maintenance department are the high costs of keeping a dedicated, highly skilled maintenance tasks on payroll. Since management of many businesses considers maintenance a necessary expenditure, rather than a possible investment option to improve continuity and efficiency of production, the focus lays on lowering the high costs associated with a dedicated maintenance department. A possible solution to this problem is training operators to conduct some of the maintenance tasks like cleaning and lubricating their equipment. This relieves the maintenance department from some of its duties, and allows them more time for preventive maintenance. The increased focus on preventive maintenance will then result in fewer corrective maintenance tasks to be conducted, and reduces the total maintenance budget.

2.10 Operators conducting routine maintenance tasks

The relation between operators and maintenance engineers was often adversarial. Efficient production depends on both production and maintenance activities. The maintenance department will have difficulty improving the lifespan and dependability of assets when the operators see the maintenance department as 'you operate, I fix'.[85]

This adversarial relationship was possible in the early days of industrialized production where equipment was often labour intensive, and maintenance didn't necessarily halt production. The,

[83] Finch, B. J., & Gilbert, J. P. 1986, p450
[84] Murthy, D. N. P., Atrens, A., & Eccleston, J. A. (2002), P294.
[85] Yamashina, 1995, p36

often large, equipment had a lot of redundancy built in to ensure continuous operation. With a higher dependency on production equipment and higher production speeds, competitive manufacturing is requires that operators can participate in the maintenance function by becoming responsible for the prevention of deterioration. Since operators are working with the equipment, they play a central role in equipment operation, condition, and maintenance. The information held by operators on the condition of the equipment allows maintenance personnel to focus their energy on tasks requiring their technical expertise and to expand their knowledge on more sophisticated techniques for advanced manufacturing.[86]

As a vital part of TPM, Autonomous Maintenance (AM), or Jishu Hozen (JH) in Japanese, transfers the low-technical maintenance activities to production operators who then maintain their own equipment independently without notice or instruction from the maintenance department.

When implementing the AM programme, it is prudent to start with one or two critical machines or operating equipment. The criticality level of these machines or equipment should be used to select what machines or operating equipment should be used to begin the programme.[87]

Starting the AM programme with one or two critical machines or equipment is prudent. The main criterion of the machine or equipment selection is based on the criticality level.

Labib (1998) measured the critical level of the machine or equipment based on the breakdown time and its frequency. Therefore, using simple statistical techniques, such as a histogram or Pareto diagram, the critical machine or equipment can be identified. Selection of the right equipment during the initial stages of implementation to the entire AM programme is provided. This is also accomplished to ensure that the AM programme is able to achieve the established goals before being implemented to another machine or equipment, and consequently to the entire shop floor.

Pillar one of Total Preventive Maintenance, Jishu Hozen, is a methodology which converts an operator in small, manageable steps into a maintenance man who can take care of his machines basic required maintenance.[88] Including in these steps are the initial cleaning, elimination of sources of contamination and hard-to-access areas, preparation of tentative AM standards, general inspection, and autonomous standards.[89] For a full autonomous maintenance plan, the boundaries of tasks and responsibility need to be well defined to avoid double work but also ensure that all the required maintenance tasks are conducted. This requires a full description of the required maintenance tasks, their complexity and the time they require. This information is then used to divide the tasks between the operators and the maintenance engineers. By relieving maintenance engineers of routine tasks like lubrication, cleaning, and visual inspections more time can be allocated for preventive maintenance.

2.11 Implementation of Autonomous maintenance

There are seven steps for successful implementation of Autonomous Maintenance.[90] Before implementing Autonomous maintenance, employees need to be trained for AM. Both the maintenance department and the operators need to be convinced of the benefits that TPM and AM, and the operators need to be trained on how to conduct the basic maintenance tasks on the

8686 Yamashina, 1995, p37

87 Min, C. S., Ahmad, R., Kamaruddin, S., & Azid, I. A. (2011), p11.

88 Kumar, S., & Bhushan, R. (2017), p2.

89 Min, C. S., Ahmad, R., Kamaruddin, S., & Azid, I. A. (2011), p270

90 Ngadiman, Y., Hussin, B., & Abdul Majid, I. (2013), p7

equipment they operate. When operators and maintenance engineers are convinced and trained on AM, the machines need initial cleaning and prepared. After the initial cleaning, the cleaning process needs to be well documented, categorized, and tagged. This well-documented cleaning process allows for documentation and standardisation of the cleaning process. It is important in the cleaning process that it is conducted by both the operators and the maintenance engineers. When maintenance engineers leave the equipment in a worse state as when they started necessary repairs, the process will become demoralizing for the operators. This undermines the effectiveness of AM.

The next step is to implement kaizen. In Japanese, Kai means "to take apart", and Zen means "to make good". Together, they mean to improve something by taking it apart. Kaizen is using the fundamentals of scientific analysis in which elements of a process are analysed (or taken apart) to understand how it works, and then discover how to influence or improve it to make it better. This is often done by small improvements, that improve the effectiveness of the operation, and ease the cleaning and maintenance functions. This step minimizes the amount of sources of contamination and hard-to-reach area's that need to be cleaned. These kaizen can be as small as replace a screwed down flywheel door with a hinged door. The kaizens implemented in this step should minimize the accumulation of dirt and dust in the equipment. Not only does this save time cleaning the equipment, but it also improves the operational life by reducing wear.

These kaizens are a continuous process, where small or big improvements are implemented throughout production.

When the idea of kaizens are implemented, standards of lubrication, cleaning, fastening, and inspection are formalized. Implementing autonomous maintenance often includes the use of visual controls. Visual controls is an approach used to minimize the training required to learn new tasks, as well as to simplify inspection tasks. Equipment is marked and labelled to allow operators identify abnormal conditions from normal conditions.[91]

These visual controls include colours in gauges to quickly identify if a readout is in the safe operating range, for example by implementing green background in the normal operating range. Another example might be to colour code lubrication points and match these colours with corresponding types of lubrication at the warehouse.

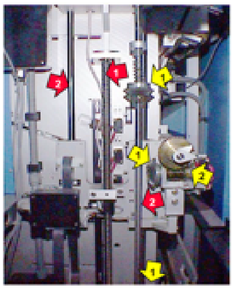
Training operators to autonomously maintain their equipment can be done with one-point training lessons. These often one-sheet lessons concern one maintenance task. One Point Lessons contain a schematic of the equipment, with clear instructions on the maintenance task. Figure 1 shows an example to a one point lesson for lubrication of equipment. Notice a clear distinction in colour matching the different types of lubrication required at different lubrication points. This further clarifies the task for the operator whilst minimizing confusion.

[91] Higgins, L. R., Mobley, R. K., & Smith, R. (2002). P135

One Point Lesson	
Equipment: ____________	Dept.: ________ date: ____________
Time: ____________	Creator: ____________
Subject: ____________	Revision date: ____________

Purpose:
Lubrication of equipment

Unloader Lube Points

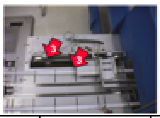


Use Light Oil Here (TSI 301 or equivalent MRO# 6200170)

1. Index Lead Screw
Monthly basis
2. Index Thompson Rods (2)
Monthly basis
3. Pusher Thompson Rods (2)
Monthly basis

Use Medium Grease Here (Mobilux EP-1 or equivalent)

1. Multi-cassette Bevel Gears (3)
Monthly basis
2. Tilt-mechanism Worm Gear
Monthly basis



Prepared by: Steve
Date: 9 July

Note: Arrow color matches markings on machine

Training completed	Date	
	Trainee	
	Note	Colour markings match marks on machine

Figure 2 - One Point Lesson

By implementing autonomous maintenance, it is important to realize that there are a few common concerns about autonomous maintenance. First, the operators are being asked to assume additional responsibilities. The operator's performance measures should be modified to include these responsibilities. The maintenance staff is asked to give some of their responsibilities up. This can create the impression that maintenance engineers have to worry about their job security. To address these issues, management must communicate their support for the new approach, and provide the opportunity for maintenance engineers to assume new responsibilities, for example to implement condition based testing or to focus more on preventive maintenance.[92]

[92] Higgins, L. R., Mobley, R. K., & Smith, R. (2002), p135.

3. A DISCRIPTION OF THE CURRENT AND DESIRED STATE OF MAINTENANCE

At Unilever Sourcing Unit Nassaukade they were in the process of replacing the last 60 year old packaging machines that had been packaging margarine since the fifties. The main reason for replacing these machines was not because the new machines were faster, since this wasn't the case. Nor because they weren't efficient. The reason was that the old continuously operating machines were a lot harder to maintain and required special skills than the new, modular, stop-and-go machines. Most of the maintenance tasks on the new lines could be done with autonomous maintenance, while the old lines needed specialized maintenance, and increasingly scarce expensive parts.

This shows the evolution in maintenance mentioned in the previous chapter. The new lines, for example the HAMBA line, were operating in a stop-and-go motion. This meant that for every step, the line stopped momentarily allowing the step to be completed. After the step was completed, the line moved to the next step and stopped again. This allowed for a modular design, and easier maintenance.

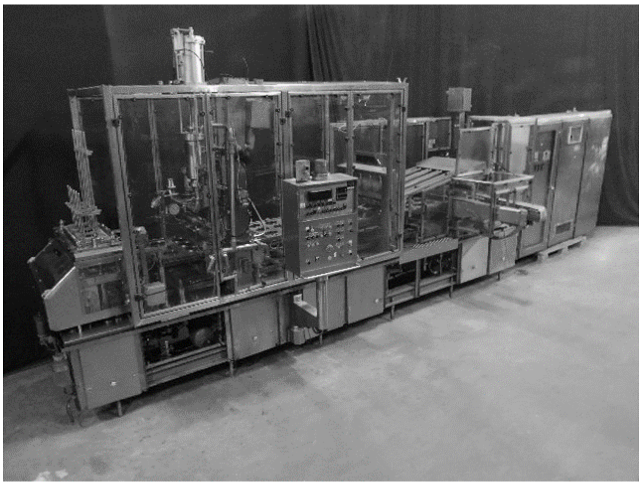


Figure 3 - HAMBA line

[93]

[93] HAMBA, 2017

The old SIG lines operated continuously. The steps were designed to follow each other seamlessly. This allowed the machine to run continuously without the previously mentioned stop-and-go motion. The upside of this method is decreased wear on the parts since they didn't need to stop and start several times a second. The downside was that everything was interlinked, and specialized knowledge of the line was required to maintain it.

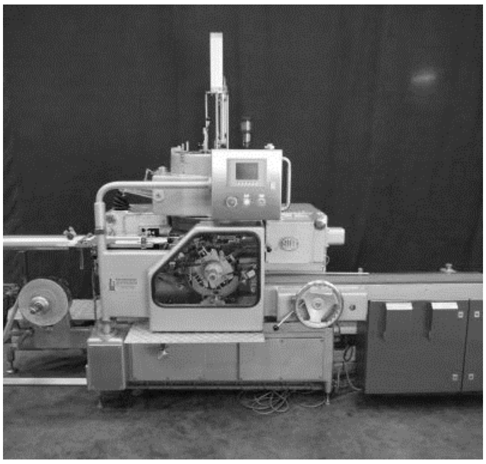


Figure 4 - SIG packaging line

94

The choice to move to the new machines was looking at the future. The modularity allowed for parts to be replaced at the line with a new or refurbished part, and the worn parts to be repaired off-site, allowing for minimal production downtime.

At the peanut butter side of the factory, the original mill from 1948 was still used. This was a heavy, cast iron housing with milling plates that are adjusted according to the desired type of peanut butter. For the crunchy type, the plates are adjusted a little further apart, but the recipe and production process hasn't changed since the introduction of peanut butter in 1948. This shows the evolution of the production process and maintenance strategy in one factory. From the break-down maintenance of the mill, and the continuous production, to the efficient, easy to maintain modern lines recently purchased.

In this chapter, the production process of margarine at Unilever Nassaukade is explained to give an insight in the different types of production assets used.

Then the maintenance organisation is described to give an insight in the type of maintenance strategy and the maintenance department at Unilever Nassaukade. Further the Central division where this research was focussed and the maintenance process is discussed.

3.1 The production process at Unilever Nassaukade

The production process at Unilever Nassaukade comprises of three different departments.

At the first step, the raw materials arrive at the Central Department. My work at the maintenance department at Unilever Nassaukade mainly focussed on this central department, where I worked on the use of the CMMS, which will be discussed later. At the Central Department, the raw materials arrive in either liquid form, like rapeseed or sunflower oil, or in powdered form, such as cornflower.

[94] SIG machine, 2017

The liquid oils are stored in large silo's until they are needed for production. Then they are pumped in mixing vats where they are mixed with other ingredients. This process takes approximately half an hour.

After the mixing step is completed, the product is pumped in the final mixing vat, where the product is mixed to the final specifications.

The contents of this mixing tank are then pumped to a crystallizer where liquid ammonia is used to cool the product. The product is then crystallized further until solidified.

After this step, rotating knifes scrape the margarine off the sides, and the product is pumped to the packaging line.

3.2 Three different maintenance structures.

There are three different maintenance structures at Unilever Sourcing Unit Nassaukade. The first structure is preventive maintenance, where objects are maintained preventively to avoid breakdowns and ensure continuity of the production process. These preventive maintenance activities are performed at strategically important production objects at scheduled times. When the

The second maintenance structure is planned corrective maintenance. This type of maintenance is conducted when a fault is detected, but direct attention is not needed. The asset is than labelled for maintenance to be conducted at a more convenient time.

The third type of maintenance is unscheduled corrective maintenance. This type of maintenance is for critical components that have broken down and require immediate attention, often due to a production stop followed by the equipment breakdown.

3.3 Maintaining the assets in the Central Department is both important as difficult

This research is confined to the Central Department of the factory at the Nassaukade. This is a very crucial part of the factory, since an outage here will result in an immediate halt of production throughout the factory. The high impact of this department means that the maintenance must ensure continuity of operation at all times, and makes planning maintenance tasks difficult. Working in these conditions also brings high risk levels. When maintaining these assets, safety precautions are required which take time. This time must be factored in when planning for maintenance, both opportunity based and preventive maintenance. All these factors make the Central Department of the factory a sensitive and hard to plan area to maintain, while the high dependability of the factory on this department makes keeping the assets in working and dependable condition extremely important.

There are three different types of maintenance tasks at SUNK, namely Preventive maintenance, planned corrective maintenance, and unplanned corrective maintenance.

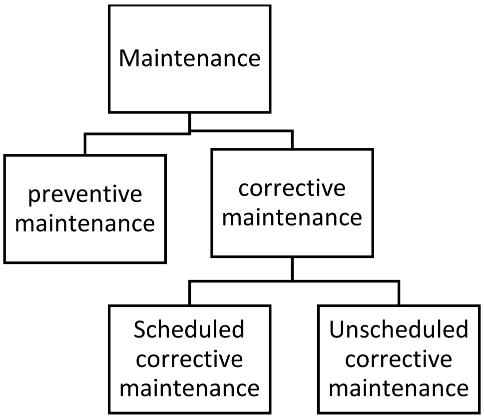


Figure 5 - Maintenance types at SUNK

Preventief Onderhoud (PO, Preventive maintenance). This type of maintenance was planned in advance to avoid the need for corrective maintenance. These planned preventive maintenance tasks can be divided in two categories. The first type of PO work order can be conducted during opportunities or even during production when an operator has spare time. These opportunity based maintenance tasks vary from visual inspection and cleaning tasks to routine maintenance tasks. Usually, operators contacted the Unit Technician and request what tasks are available.

The second type of PO is scheduled maintenance requiring a production stop. These types of maintenance are well planned and scheduled beforehand, to minimize the impact on production capacity. During these stops, the equipment is restored to an as-new condition, ensuring continuous dependability until the next scheduled maintenance stop.

Gepland Correctief Onderhoud (GCO, Planned Corrective Maintenance). This type of maintenance was used when a defect of a production asset was detected, but there was no pressing need to maintain the asset immediately. These defects were labelled, and maintenance was scheduled at a time when it was possible to maintain the asset in concurrence with production. When a fault is detected that does not require immediate attention, a label is attached to the problematic equipment and the fault is reported to the maintenance department.

An example of when this type of maintenance was used is when there was a small leak on a valve. This leak must be fixed in a relatively short time to avoid further leaking and spilling of material, but does not require immediate shutdown. In such a case, the fault was labelled, indicating that it was noticed and registered for maintenance. The required maintenance task is then scheduled in accordance to production and the required materials and tools are prepared. Once the maintenance task is done, the label is removed and the equipment is registered.

3.4 Flow chart Maintenance stop

Ongepland Correctief Onderhoud (OCO, Unplanned Corrective Maintenance). This type of maintenance was to be avoided as much as possible, since this was only used when an asset broke down, halting production, and was therefore in immediate need of repair. Assets with lower levels of priority could be run at break-down-maintenance since a halt of production in these departments didn’t immediately affect production.

At the beginning of this study, the reorganisation of maintenance was one year ago, and the intention was to make a clear maintenance strategy with the use of the CMMS available. There were maintenance tasks implemented in the system, but the current maintenance schedule was planned in an Excel sheet with broad estimates and vague task descriptions. The intention was to transfer all known maintenance tasks in a CMMS system, with cross references to estimations on time, cost, and an exhaustive list of materials required for the scheduled maintenance. This would then be further expanded with experiences during the year to create an exhaustive maintenance schedule, which could be used for better equipment monitoring and planning of maintenance tasks.

For the annual schedule in Excel, there were two different sheets. One to indicate the investment in time required for the scheduled maintenance task, and one with cost estimations for the scheduled tasks.

These schedules were used as a guide to when and where maintenance must be conducted, and acted as a scheduling tool for maintenance managers and unit technicians. The excel sheets were also used to give an estimated required annual budget on maintenance.

The factory was in the process of fully utilizing the CMMS API-Pro within the factory. This would be done in three phases.
The first phase would be to model all operating equipment in the system. The second phase would be to transfer all known maintenance tasks, preventive and corrective, in the system. The third phase would start utilizing further capabilities of the system as condition based maintenance and the mobile applications.

With predictive maintenance, many maintenance tasks are known in advance. This allows both for planning them, but also allows for the management of the execution of these tasks.

The maintenance tasks defined in the interview phase were further developed and ordered in (x) different categories. (monitoring, installing new equipment, restoring equipment, replacing wearables, cleaning). These categories were then implemented in the system, to further evaluate their priority. This can also help to manage the maintenance of the equipment.

3.5 What needs to be done to define maintenance and assign priorities to them?

Prioritizing the production assets to be maintained is an important step in formulating the maintenance strategy. This is then used to determine the level of maintenance required. At Unilever Nassaukade there were two major categories in determining how the asset was maintained. The first category was the necessity for production shut-down. This was then divided in shutting down an entire production line, resulting in scheduled preventive maintenance. The second category was when it was possible to maintain an asset while producing in another part of the line. For example, it was possible to maintain some of the mixing vats, when there was sufficient product in the vats on the line. This didn’t require production to be stopped, and allowed for more flexibility in scheduling maintenance. Thirdly were the assets that do not require production to be stopped at all to be maintained. This included the run-to-break assets.

jaarplan gepland onderhoud €	Prio 1 2 3 4	prio	1	2	3	4
MFCEN-Algemeen	nooddouches					
	algemeen	4				
MFCEN-OIL-Autolos	autolos 1	3				
	autolos 2	3				
	autolos 3	3				
	autolos 4	3				
	autolos sterol	3				
	autolos rp70	3				
	kadelos	3				
MFCEN-OIL- Ontlucht	ontluchter 1	3				
	ontluchter 2	3				
	ontluchter 3	3				
	ontluchter 4	3				
	heater 1					
	heater 2					
	heater 3					
	heater 4					
MFCEN-OIL- fixtanks	fixtanks	1				
	pompen	1				
MFCEN-OIL- mixbrug	oliering 1	1				
	oliering 2	1				
	oliering 3	1				
	oliering 4	1				
	oliering 5	1				
	oliering 6	1				
	oliering 7	1				
	oliering 8	1				
	oliering 9	1				
	oliering 10	1				
	oliering 11	1				
	oliering 12	1				
	oliering 13	1				
	oliering 14	1				
	oliering 15	1				
	oliering 16	1				
	oliering 17	1				
	oliering 18	1				
	oliering 19	1				
	oliering 20	1				

Figure 6 - Maintenance priorities assets

3.6 The differences between modelled maintenance and actual maintenance

During my research at Unilever Nassaukade I was tasked aiding the maintenance technician in preparing for the maintenance stop, participating in the maintenance stop, and documenting the stop in the CMMS.

This particular maintenance stop was scheduled to clean and inspect the pipes and refurbish the valves at the very end of the production process in the Central Department, right before the semi-finished ingredients were mixed together in the final mixing tank.

These pipes were a loop from the tanks for storage of raw ingredients and mix tanks with valves at every production line where the required ingredients could be tapped, and used to produce the final product. However, there were two different types of valves. The problem was that it wasn't known what type of valve was used in what tap. This created a whole heap of problems; first of all, in preparation of the maintenance stop, material for both types of valves needed to be ordered. This resulted in nearly half the material unused. Secondly, additional time was used in registering what types of valves were present at the taps. This significantly reduced the available time for the maintenance stop, and put the schedule under strain.

Lastly, due to miscommunication, some operators forgot to register what valves where at what taps. Instead of registering exactly what valve was present at what tap, the operator registered how many of each valve were present. This information was useless when a specific valve needed replacing.

Another problem was estimating the time needed. Nobody knew how long the task of refurbishing a valve took, with estimates from as little as five minutes to half an hour per valve. This made it very difficult to determine how many valves to maintain, and finally the decision was made to prepare all valves for replacement, and refurbish as many valves as possible. Since maintenance time was very limited due to the entire shutdown of the factory, the cost of flushing all the lines was

4. DEVELOPING A MAINTENANCE MODEL FOR UNILEVER NASSAUKADE

After describing the current methods of maintenance at Unilever Sourcing Unit Nassaukade, this chapter analyses the maintenance strategy currently in place. While the structure and assets of the Unilever Sourcing unit Nassaukade were discussed in the previous chapter, in this chapter the underlying strategy and method of maintenance is analysed.

4.1 What is the maintenance task that needs to be done?

Planning maintenance commences with a good descriptions of the maintenance tasks required to ensure continuous operation of production equipment. The nature of these tasks can vary from inspections like visual inspection or condition based testing, to complex preventive maintenance tasks. By defining what maintenance tasks are required for a specific asset, a schedule can be made with those tasks and the frequencies they need to be conducted.

A second estimate that needs to be made is to evaluate what party can conduct the maintenance task. It will be very wasteful to assign every maintenance task to maintenance engineers, while operators can conduct the basic maintenance tasks like visual inspection, tightening of bolts, and lubrication themselves through autonomous maintenance.

If a maintenance task is defined, the materials and conditions needed for a successful completion of the task are described.

Most maintenance tasks in the factory require operators to first secure the section they're working on. Securing the section is done by a 'lock out tag out' principle. This ensures clarity on the locked down area.

Good definition of the required maintenance task results in better execution of the task.

When creating a new work order there are several attributes attached to the order.

First there is the description of the task to be conducted.

This is a detailed description of the maintenance task to be conducted. On these descriptions is detailed information on the components of the object that is serviced, like valves or lubrication points. These are often accompanied with a checklist to ensure that all the desired maintenance activities are carried out, and the entire system is ready for the maintenance task. This also prevents that a safety step is forgotten, which can have very serious consequences. Also attached to the work order are one-point-lessons for the different lock-out tag-out actions required, lubrication points with the required type of lubricant and other relevant information.

Second, a detailed material list of the object to be maintained is attached. On schematic is indicated what components are inside the object, and what type they are. This prevents a wrong type of valve lining to be placed in a valve and ensures the quality of the maintenance task that is conducted.

When the task is completed, the work order is registered in the CMMS, so that it is known what is and what is not maintained.

4.2 What is the priority for this maintenance task?

An important aspect of scheduling for maintenance is to realize the impact of the maintenance action on the production. Tasks that require production shutdowns are preferably done during times when there is no production, or during days that are scheduled for maintenance of operating equipment. Tasks with lower production impact might be scheduled during opportunities, but the impact of the maintenance action will have to be very well defined in terms of time and dependencies to avoid disruptions in production.

The Central department transports ingredients and semi-final goods to the production department. These ingredients and semi-final products are used by one or more production lines simultaneously, and disruptions in the central department on a single asset can directly shut down the entire production department. For this reason, the assets in the Central Department were given priorities, based on the impact they have on production.

Level one priority maintenance tasks are assets that have direct effect on the entire production facility. An example of this type of asset is the bridge that houses the loop of pipes that are used to transport the required ingredients to the required production lines. This loop consists out of 20 tubes that transport a specific type of oil- or water based product to the production department for processing. The loop runs past all production lines, with a valve at each station to allow tapping the required ingredient in preparation of production. A broken valve would immediately disrupt the use of the entire tube in the loop, halting production. Replacing or repairing the valve also requires the draining and rinsing of the tube, wasting a significant amount of material. The combination of these factors makes it preferable to replace all the valves on the loop simultaneously, requiring draining the line only once and guaranteeing dependability of the valves during production.

Other assets within the Central Department would disrupt production when shut down, but not the entire factory. These assets are used for the production on certain production lines, which would be shut down in the event of a problem with the asset, but the effects are limited to these production lines, and other lines would be able to operate normally. An example of this would be the disruption of a buffering tank. Buffering tanks are used to store ingredients for production until they are required. In combination with the mixing tank used to prepare semi-finished goods, they are linked to the required production lines. If a buffer tank is down due to faulty parts they disrupt the production lines that use the product stored in the buffer tank, but won’t disrupt the entire production facility. Therefore, this is defined as a priority two.

Assets that are used in production of specific products, but won’t otherwise halt production when down are labelled as level three priority. Even though production of certain products will be impossible when these assets are down, the production capacity that was reserved for production of a specific product can still be used for the production of another product, resulting in no loss of overall efficiency.

The fourth and last priority level is assigned to assets that can be maintained during production.

For the maintenance on level one to level three assets, production needed to be, at least partially, halted or postponed. For level four priority, maintenance can be conducted while production continues.

5. COMPARING MAINTENANCE STRATEGIES

To compare the findings at Unilever Nassaukade, surveys were send to the maintenance manager of Unilever Nassaukade, and to ten other Unilever sites, with replies from two Unilever factories. The Haifa plant in Israel produces savory, dressings and spreads. The Purfleet site in the United Kingdom produces spreads, dressings and mayonnaise. Both of these sites are in the BCS business unit of Unilever, which stands for Baking, Cooking, and Spreads.

The results of these surveys were analysed for both similarities, and differences between the respective sites in relation to maintenance strategies used.

The survey consisted of four parts, each consisting of five questions designed to compare the different maintenance strategies and implementations on the respective subject.

The first part acted as an introduction, and determined if the different types of maintenance strategy discussed in this paper were used at the site, and to what extent.

The second part focused on autonomous maintenance. Since Unilever is employing WCM, it is no surprise that all the responding maintenance managers used autonomous maintenance. However, there were differences in the way autonomous maintenance was implemented, which will be discussed later in this thesis.

The third and fourth part aimed to study the balance between the corrective and preventive maintenance tasks. These different types of maintenance were studied in terms of cost compared to the total maintenance budget, and what maintenance tasks were most common for corrective maintenance or preventive maintenance respectively. For both these parts of the survey asked how the maintenance tasks were documented and what Key Performance Indicators (KPI's) were used to measure the effectiveness of the maintenance applied.

The fifth part of the survey aimed to investigate to what extent external, or contract maintenance was employed. This was measured by asking similar questions as posed at chapters three and four. This was done in an effort to create as much similarity between the corrective, preventive, and outsourced maintenance sections, thus creating more comparable results.

The last part comprised of five open questions. This part was added to gain further insights not found with the quantitative questions posed in the first five parts of the survey.

The results are discussed in the parts below, which are organized in the same way as the survey.

5.1 There are different implemententations of autonomous maintenance.

At all three sites have specialized training and OPLs designed to train their operators on autonomous maintenance. The different implementations of autonomous maintenance indicate that successful outcomes of autonomous maintenance can be achieved through different methods of implementation.

Addressing the issue of documenting autonomous maintenance, it was hypothesized that autonomous maintenance was documented through the involved parties, detailed task descriptions, historical data and (spare) part availability.

In reality, only one out of three sites actually document autonomous maintenance in the CMMS, and only by attaching the inspection lists to the corresponding planned inspections. The other two sites do not document the autonomous maintenance in their CMMS, but rather allow time for autonomous maintenance and prepare the tasks.

This does not implicate that autonomous maintenance is not measured or checked. All three sites use KPI's to check if the autonomous maintenance is conducted correctly.

What is surprising, however is that even though all three sites use checklists to ensure all required maintenance tasks were indeed done, only two of the sites had created OPLs to aid the operators in the completion of these tasks and avoid mistakes.

Futher implementation of Autonomous maintenance by use of visual inspections however, is only used at one site.

5.1.1 There are major differences in time available to operators for Autonomous Maintenance.

One result that stood out when investigating Autonomous maintenance at the sites was that the time available to operators for the required maintenance tasks varied from 1-3 hours at one site, 3-5 hours per week at the second, to more than 5 hours per week at the third site. Keeping in mind that this includes the visual inspection, cleaning, and checking of the general condition of the equipment, the variance of time available is surprising.

This means that while at the first site, it creates the impression that autonomous maintenance is a task that is conducted when extra time is available at one site, there is almost an entire day available for autonomous maintenance tasks at the other site.

This variance in allotted time across the three sites can indicate the value given to autonomous maintenance tasks. It is possible that autonomous maintenance tasks are conducted more efficiently at one site, but results indicate that different levels of emphasis put on autonomous maintenance tasks at the three sites.

There is a clear difference in the percentage of operators currently involved at autonomous maintenance. While 75-100% of operators is involved at autonomous maintenance at one site, at the other two sites the participation level is 50-75% or even 25-50%.

5.2 Differences at corrective maintenance.

Even though a goal of every maintenance department is to minimize the use of corrective maintenance, the need for corrective maintenance cannot be fully avoided.

The results found in this case study indicate great variances in the use of corrective maintenance throughout the sites.

A first indication to this variance is the percentage of the total maintenance budget that is spent on corrective maintenance. While the use of autonomous maintenance, preventive maintenance, and contract maintenance is expected to influence the amount of corrective maintenance required, one site spend as much as 50-75% of its total maintenance budget on corrective maintenance tasks. With the lowest percentage of total maintenance budget spent on corrective maintenance tasks totalling 0-25% of the total maintenance budget, and the third site spending 25-50% of its budget on corrective maintenance, the differences between the sites on corrective maintenance are significant.

This also becomes apparent in the time spent on corrective maintenance. While two sites indicate to spent around 25-50% of the total time on maintenance conducting corrective maintenance tasks, the third site spends 0-25% of the time spend on maintenance conducting corrective maintenance tasks.

The corrective maintenance tasks are documented in the CMMS at all three sites. However, while all three document the corrective maintenance task conducted, two of them include to update the maintenance schedule on the respective task. If, for example, a valve is replaced, the timer on the replacement of the valve is reset after the corrective maintenance task.

There are different KPI’s on the corrective maintenance task to measure its effectiveness. While two sites measure total downtime and cost, only one site records the time spent on the actual maintenance task and the response time. The third site indicates that it has no KPI’s on corrective maintenance.

5.3 Preventive maintenance practices at the three sites

Preventive maintenance can be planned, scheduled and budgeted. This makes the preventive maintenance conducted in sites manageable, with better preparation, part availability and documentation of the conducted maintenance activities.

While all three of the sites document maintenance schedule in the CMMS, as well as the time spent on maintenance activities, only one site also documented what engineer/operator was involved with preventive maintenance, and employed the use of Lock-out Tag-out protocols.

This is also apparent while looking at the KPI’s of preventive maintenance. Time spent on the planned maintenance tasks is measured at two of the sites. Those sites also compare the scheduled tasks with the tasks that are actually performed. One of those sites also has KPI’s for part availability during preventive maintenance stops. The third site only listed cost of preventive maintenance as a KPI.

Unfortunately only two of the sites listed their schedule for planned maintenance stops, however, the maintenance stops scheduled vary between these sites. While one site has 3-4 maintenance stops per year, the other site has one five-day slot for spreads, four five-day slots for DCA, and two five-day slots for mayonnaise. Keep in mind that this site also allows operators more than five hours weekly to work on autonomous maintenance tasks, it will be interesting to see how this affects the site.

With comparable products being produced at all three sites (all spread related) the most conducted maintenance tasks are performed on mechanical or electrical components like valves, or PCBs. This allows for better comparability on maintenance strategies.

5.4 Contract maintenance

The level on which contract maintenance is used varies per site. One site spends 25-50% of its maintenance budget on contract maintenance, while the other sites spend 0-25% of their total maintenance budget on contract maintenance.

As discussed before, contract maintenance can be used for temporarily increasing workforce, employ skilled and licenced workers, and for mandatory OEM maintenance. Another benefit of outsourcing maintenance is the extra time created to focus on core maintenance tasks. This is shown in the results since all sites indicate that the total time spent on contract maintenance is only 0 – 25%.

While contract maintenance is not documented in the CMMS at one site, and another site lists contract maintenance in a technician document. The third party lists what party was involved, what parts were used and the full history of the work done.

What is surprising is that while the first site does not document contract maintenance in its CMMS, it does have KPI's on contract maintenance on what party is involved, what employees that party sent, and what tasks were conducted. The site with documentation on contract maintenance in its CMMS only lists the party involved as a key performance indicator, and the last site lists what employee was sent by the contract maintenance party and uses historical data.

5.5 Results of survey

Table 2 Key Performance Indicators on maintenance

	Autonomous maintenance	Corrective Maintenance	Preventive maintenance	Contract maintenance
Site 1	Checklists	Total downtime Cost	Cost	What employee is sent by the third party Task Party involved
Site 2	Checklists One Point Lessons	Time spent Response time Total downtime Cost	Time spent Planned compared to actual tasks completed	What employee is sent by the third party, History
Site 3	Checklists One Point Lessons Visual inspections	There are no KPI's on corrective maintenance.	Time spent Part availability Planned compared to actual tasks completed	Party involved

Site 3	Not documented in the CMMS	Task Material list Schedule	Time of maintenance task Schedule Engeneer/operator conducting maintenance	Party involved History Parts required
Site 2	Not documented in the CMMS	Task	Time of maintenance task Schedule	my technician document
Site 1	Inspection lists	Task Schedule	Time of maintenance task Schedule Lock-out Tag-out	not done
	Autonomous maintenance	**Corrective Maintenance**	**Preventive maintenance**	**Contract maintenance**

Table 3 Documentation in CMMS

6. CONCLUSION

When I started this project, I suspected that since all three sites use World Class Maintenance, and operate in similar conditions, the differences in maintenance strategy would be minimal. However when analysing the results of the survey, I found that this was not true.

The ratios of maintenance spending for example were greatly different for the three sites as seen in the figure below.

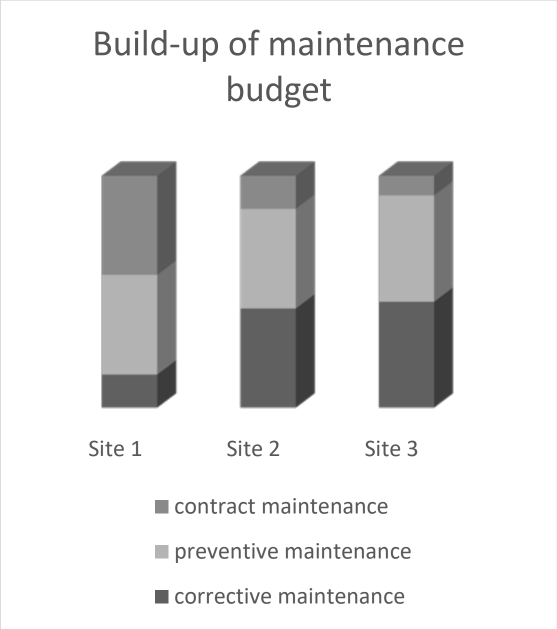


Figure 7 Maintenance budget buildup

	Site 1	Site 2	Site 3
corrective maintenance	0-25%	25-50%	50-70%
preventive maintenance	25-50%	25-50%	50-75%
contract maintenance	25-50%	0-25%	0-25%

Table 4 Buildup of maintenance budget

Even though all three sites have comparable budgets for maintenance, the build-up of the maintenance budgets varies.

Where sites 2 and 3 have similar expenditure on the different types of maintenance, site 1 has surprisingly less expenditure on corrective maintenance, and more on contract maintenance.

In this chapter, I will discuss the findings and how the choices made affected the maintenance strategy by analysing the results in corrective, preventive, autonomous, and contract maintenance and comparing them to the findings of the theoretical framework.

6.1 Corrective maintenance

Corrective maintenance is needed when a production asset has broken down and has to be repaired. This often results in production delays and the short available time for the repair means that this type of maintenance is expensive. Therefore, even though due to unforeseen circumstances like human error or undetected wear, the need for corrective maintenance will always exist, the amount of corrective maintenance preferably is as low as possible.

Of the three sites questioned, the first site (Sourcing Unit Nassaukade) has a very low amount of corrective maintenance compared to preventive and contract maintenance. The other two sites barely used any contract maintenance, and have much higher corrective maintenance costs.

Another surprising result is how corrective maintenance is registered in the CMMS as seen in table 4.

	Nassaukade	**Haifa**	**Purfleet**
Task	√	√	√
Schedule	√		√
Material List			√

Table 5 Registration corrective maintenance in the CMMS

Even though all three sites register the conducted corrective maintenance task in the CMMS, only Sourcing Unit Nassaukade and Sourcin Unit Purfleet register the schedule containing the time until the maintenance task was completed and the time it took to take action.

Lastly, only Purfleet registers the material used in the corrective maintenance stop.

While when corrective maintenance is needed, timely action is important, it is very beneficial to register the conducted maintenance, schedule and materials used.

Trends can be discovered when analysing this data, which can be used in the organisation of preventive maintenance. If, for example, it is shown that a certain asset is prone to failure, inspections on higher risk parts of that assets can be conducted more frequently. Another option is to start with condition-based maintenance on the asset, thus giving greater insight on when the asset will break down and allow maintenance technicians to service the asset before the breakdown occurs.

6.2 Preventive maintenance

When I was preparing the maintenance stop at Unilever Sourcing Unit Nassaukade, I expected that several KPIs would be used to evaluate the effectiveness of the maintenance stop. There was a great surprise for me to find out that while the objectives of the maintenance stops were clear, the details of the maintenance stop were surprisingly vague.

When determining what linings were needed in refurbishing the butterfly valves, it was not known what type of lining was currently used in the valves.

To register this information in the CMMS, I asked the operators involved in the maintenance stop to register what type of liner they put in the valve. While some operators did not register this information, I was able to determine the type used in most of the valves by looking at the liners used in the other valves, and comparing them with the total liners used of each type.

Another surprise form me came when I wanted to register how much of the scheduled tasks were actually be done. When the maintenance stop was done, and the factory was operational again, only half of the valves that needed refurbishing were actually refurbished while preparations were made for all valves. This included lock on and tag on, flushing the pipes, and then restarting the entire system.

As a result, I wondered if the time spent on maintenance was registered and used in the organisation of the next maintenance stop.

This lead to my curiosity in what types of KPI’s are used at the other site, the results of which can be seen in table 5 below.

	Nassaukade	Haifa	Purfleet
cost	√		
time spent		√	√

planned vs actual taskes completed		√	√
part availability			√

Table 6 KPIs on preventive maintenance

These results show what I suspected as Unilever Sourcing Unit Nassaukade only looks at the cost of preventive maintenance, while Haifa and Purfleet also register the total time spent and the maintenance tasks completed versus the maintenance tasks scheduled for the maintenance stop.

When questioned how many maintenance stops were conducted during the year, further differences became apparent.

Where Unilever Sourcing Unit Nassaukade scheduled three to four maintenance stops per year for the entire factory, Purfleet allotted one five-day slot for spreads, four five-day-slots for DCA, and two five-day slots for Mayonnaise.

Since it is safe to assume that most maintenance tasks will be comparable, the difference in time availability for the maintenance stops is significant, thus increasing the surprise on the lack of KPIs on preventive maintenance at Unileve Sourcing Unit Nassaukade.

Documenting this information gives further insight in the bottlenecks and problems with the maintenance schedule. For example, at the next maintenance stop, only part of the tubes could be prepared for maintenance. This greatly reduces preparation time, and ensures that all the scheduled maintenance is actually conducted.

When it is recorded what type of materials are used during a specific maintenance stop, that information can be used during the next maintenance stop. Knowing what materials were used in the previous maintenance stop eliminates the necessity of purchasing too much materials for the next stop.

Therefore, documenting these KPIs will decrease the cost of maintenance, since maintenance can be conducted more efficiently and with less waste.

6.3 Autonomous maintenance

All three of the sites involve operators in maintenance activities, although the time allotted for autonomous maintenance tasks to operators varies greatly.

At Unilever Sourcing Unit Nassaukade the operators have up to three hours a week available to them for autonomous maintenance tasks like inspections, lubrication, and tightening.

When I was making the inspection lists at Unilever Sourcing Unit Nassaukade, the Central Department was divided in areas. Each team of operators, with three operators per team, was assigned an area. The idea of these areas was that the operators responsible for these areas would not have to inspect the entire Central Department, but had to focus on the assigned area. The extra time they could spent on that area would then result in a more precise inspection, leading to a more accurate visual inspection.

Another benefit of tasking specific shifts with responsibility for inspecting ‘their’ area is that it avoids that certain areas were inspected double, while other areas weren’t inspected at all.

This was currently the case with leaks at some pipes immediately inspected, while tanks that were not present in the factory were rarely inspected, if at all.

After a trial run of the inspection list I estimated that it costed around half an hour to an hour for an operator to inspect one of those areas.

When the operators were assigned three hours a week, this would leave them with two hours for other types of maintenance such as lubrication and tightening.

In comparison, the Haifa site allowed three to five hours per week available to an operator for autonomous maintenance.

Purfleet allows the most time for autonomous maintenance, with operators spending more than five hours per week on autonomous maintenance tasks.

A problem with documenting the time spent on autonomous maintenance tasks is the accuracy of this metric. While it can be estimated that an inspection round costs approximately an hour, the various maintenance tasks an operator conducts during the shift are harder to measure.

An operator might take five minus to apply lubrication to a lubrication point, but if he needs to do this twelve times a day, it would add up to five hours of maintenance. Since it is not uncommon for an asset to have twelve or more lubrication points, this can easily be the time needed to maintain an asset.

Therefore, while three hours a week to conduct autonomous maintenance could be improved, this number might increase when taking these small tasks in account.

6.4 Contract maintenance

The reason for hiring external maintenance at Unilever Sourcing Unit Nassaukade two reasons were given. First, they wanted to hire expertise for certain projects. Secondly, external maintenance was hired to increase manpower during maintenance stops. Given the recent reorganisation drastically decreased both the availability of maintenance personnel and the allotted time for maintenance activities, hiring external maintenance personnel to aid own personnel during maintenance stops is a logical step in reaching the maintenance targets.

This also became clear when talking to staff within the central department. One of the ideas behind the reorganisation was to hire external staff during the maintenance stops, rather than employ them full time.

The results of the survey show that the other two sites have not chosen to follow this path, but rather rely on own personnel when possible. The Unilever sourcing unit in Haifa even declared not to hire external personnel for maintenance activities at all, where the Purfleet site only hired external personnel to hire otherwise unobtainable experience.

While it is efficient to only hire experienced staff when they are needed instead of employing maintenance staff for the full year, it does require maintenance to be better documented since there is no guarantee that the contracted party will send the same people.

The outsourced maintenance needs a well-documented task description to ensure that the required maintenance is actually conducted. With the maintenance tasks well described in terms of time needed to conduct the task, materials needed, skills and licences of the person conducting the task, LOTO procedures, and food safety regulations.

This information can then be used in negotiations for outsourced maintenance and evaluating the maintenance performed by third parties, but only when these aspects of the task are documented

Documenting the performed maintenance by third parties for preventive maintenance requires Unilever Nassaukade to have more KPIs in addition to cost.

The KPIs of time spent and planned vs actual performed maintenance used at Haifa and Purfleet are examples of good KPIs when documenting the efficiency of maintenance conducted by third parties.

6.5 The reorganisation greatly increased the need for documentation.

The reorganisation at Unilever Nassaukade had great impact on the maintenance strategy. The reduction in availability of time and resources forces the maintenance department to operate more efficiently with the remaining resources.

In the year of the reorganisation an analysis of maintenance requirements within the Central Department was made with estimations on what maintenance needed to be conducted, and what the cost of these maintenance tasks would be. However, most of the entries were educated estimates but it was very useful for me while working with the CMMS.

The lack of documentation should be quickly resolved if the maintenance department wishes to improve the efficiency of its resources.

Despite the large reduction in resources for maintenance, Unilever Sourcing Unit Nassaukade spends a remarkable low portion of its budget on corrective maintenance, with Purfleet and Haifa spending a significantly higher part of their maintenance budget on corrective maintenance activities.

This is especially surprising considering the fact that Sourcing Unit Nassaukade has the least available time for maintenance stops. An explanation for this could be that third-party maintenance is used when corrective maintenance is needed, and therefore the cost of the task isn't registered with corrective maintenance rather then contract maintenance.

During my time at Unilever, however, I found that contract maintenance was mostly used for scheduled maintenance and specialized maintenance on, for example, equipment with liquid ammonia.

The reason to not use contract maintenance for most corrective maintenance needs was the extra time needed for the third party to arrive on site. Contacting the correct party when detecting the need for corrective maintenance and then waiting for the third party to arrive resulted in an expensive production stop. Therefore, it is preferred to conduct corrective maintenance by own staff, greatly reducing the time between the detection of the problem, and the continuing of production.

On the other side, preventive maintenance proved well-suited for contract maintenance, since their was a clear understanding of what maintenance task needed to be done, and an the time when the task needs to be done can be scheduled to avoid production stops.

Compared to the sites in Purfleet and Haifa, Nassaukade lacks documentation of the maintenance tasks. By filling the CMMS with task descriptions, materials, time estimates, preferred third parties, and other information, the maintenance strategy and schedule will be greatly improved.

With the market for margarine declining by an average of five percent per year, and the intention of Unilever to sell its BCS department, a further reorganisation of production and maintenance is not impossible. Therefore, maintenance needs to be better modelled and documented. This allows justification for and more efficient spending of the budget. While an exact budget for corrective maintenance can be hard to explain, the maintenance budget can be easer explained when indicated exactly what preventive maintenance needs to be conducted in the following year, how much time will be spent per scheduled maintenance task, why they are needed, and how much those tasks costed historically.

With all operators of the central department involved in maintenance activities, and no dedicated supporting maintenance staff, I can truly say that autonomous maintenance was fully implemented.

There was a unit technician that oversaw the maintenance and scheduled the preventive maintenance stops, but the actual maintenance was conducted by the operators.

Although the time to conduct maintenance was available, it surprised me to see that the operators didn’t performed a lot of maintenance tasks and rather moved them forward to the next shift. To remedy this situation, I created work orders with a task description in collaboration with the unit technician so that there would always be a maintenance task available when there was spare time.

These work orders varied from inspections to routine maintenance activities like lubrication. After they were done, the unit technician who registered them in the CMMS would then collect the completed work orders.

This proved to be unsuccessful with very little work orders completed. A benefit of creating the work orders was that the operators now had concrete options for their maintenance activities and didn’t needed to ask what tasks needed to be done.

It was hoped that the forming areas and assigning them to the operators of specific shifts would improve the inspection and other autonomous maintenance tasks to be conducted regularly.

7. DISCUSSION

This research was conducted in a controlled environment, and the found solution will therefore not be uniformly applicable. To fully develop a maintenance strategy within Unilever Nassaukade, further research to dependencies within the different production stages must be conducted. These dependencies can be used to develop a plan that allows for further prioritised maintenance, with the different systems targeted more specifically.

All of the questioned sites were part of the BCS division in Unilever, and a larger sample size that included sites from other concerns would improve the reliability of this study.

When I started at Unilever Sourcing Unit Nassaukade, I couldn't foresee the path my internship would take me on. The additional projects on maintenance and remodelling of the building allowed me to develop skills in recognising what information was valuable, and how to present them efficiently.

When Unilever announced its intention to sell the BCS department, I had a front row seat to what impact this had on the factory. The reorganisation was still felt throughout the factory, and many people just started to adjust to their new roles. With the bid on Unilever by Kraft Heinz, it was suspected that there would be an announcement by the board of directors to satisfy the shareholders, and Unilever had formed its BCS department due to a decrease in volumes for spreads and cooking products.

However, at the moment of the announcement, not even the top management of BCS was aware that this would happen, and had the same questions on job security, timeline, sale conditions, pension etcetera as the operators had.

My role as an intern allowed me to look at the developments and see how they had an impact throughout the organisation.

Months before the announcement I was asked to join a team that organised the remodelling of the offices to accommodate more than twice the number of people. During these meetings I learned that that remodel was needed since Unilever planned to close its research and development centre in Vlaardingen and open a new R&D centre in Wageningen to profit from the formed cluster on food technology surrounding the University of Wageningen. This was held a secret to avoid a possible brain-drain or panic situation in Vlaardingen, but when the closing of the centre in Vlaardingen was announced, it was still surprising to me how it was handled.

During the morning all communication with people in Vlaardingen, with I often communicated on possibilities for the unused equipment, was closed. When it became clear what had happened, people were shocked since many of them worked closely with employees in Vlaardingen.

The morning of the announcement that Unilever was going to sell its BCS department had a similar feeling to it. People heard about the intention on the news and were highly surprised, not in the least that they didn't hear from it from Unilever itself.

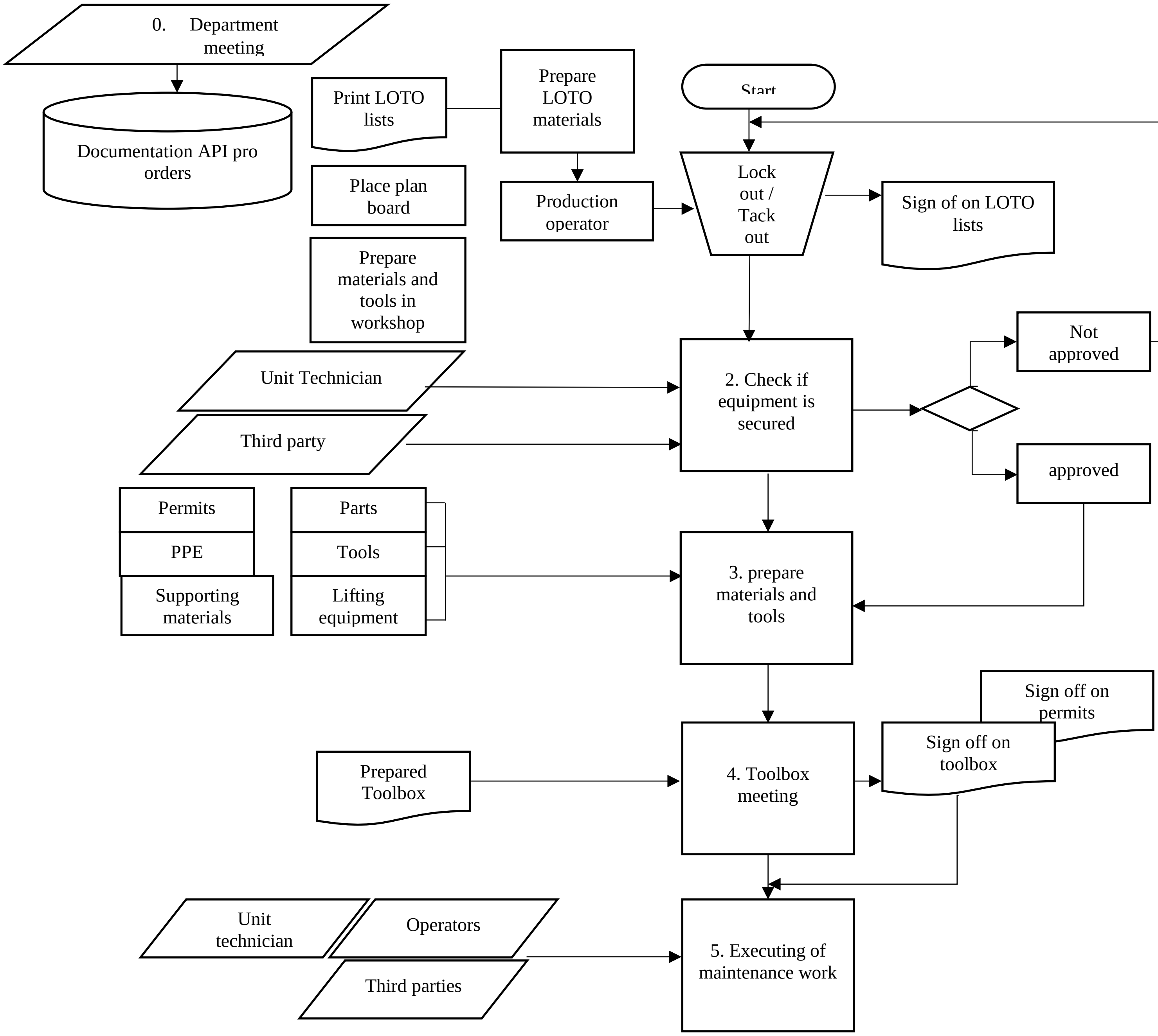
As an intern, I didn't realise how much impact this would have on my research. It became increasingly difficult to obtain information, especially if that information was on faults and problems. The surveys I needed to compare the situation at Nassaukade with were very difficult to get, especially once I left my position at Unilever and had to use my personal email address in sending the survey requests.

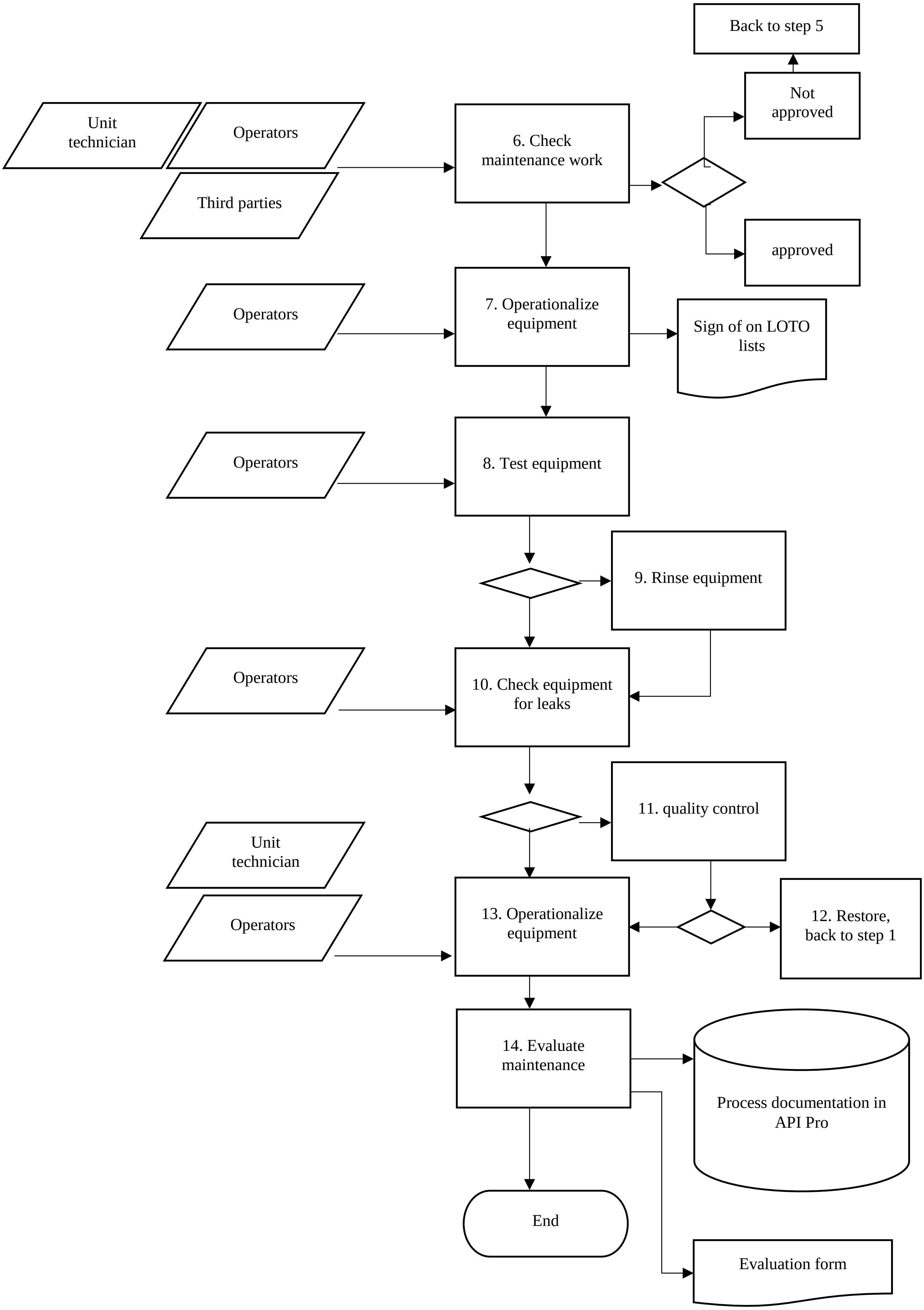
Once I had two filled-in surveys from other sites within BCS, the first thing that I noticed was how big the differences between the sites were.

Even though I expected some differences, I mostly expected similarity since all sites operated with the WCM philosophy. Especially the differences I found on corrective maintenance and contract maintenance were surprising.

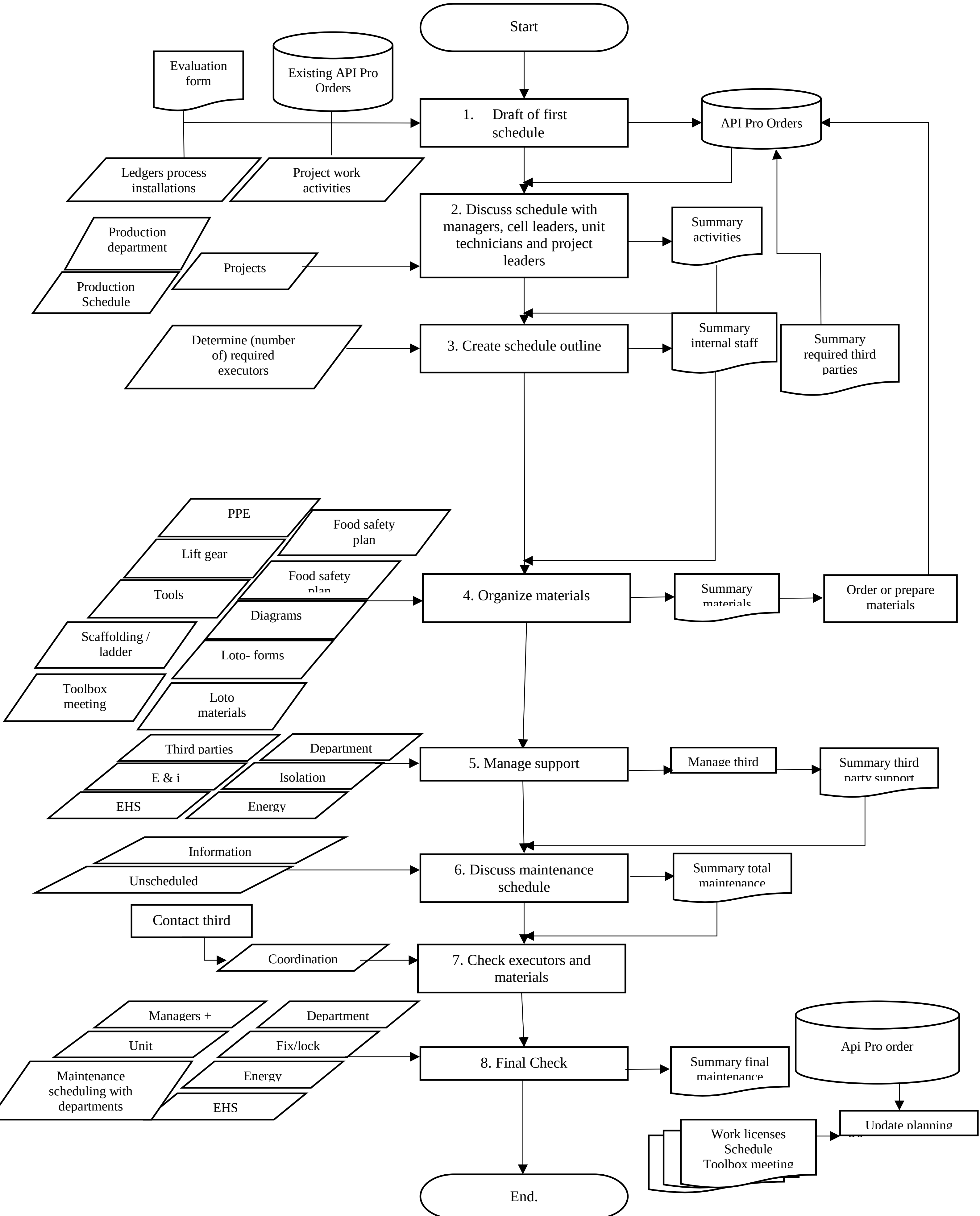
I really enjoyed working with the maintenance department, especially during the maintenance stop when I assisted with refurbishing the valves. By working in organising the stop, as well as participating with the maintenance activities, I could more accurately model the maintenance schedule in the CMMS. Another major advantage was that I could see both sides of the problem. I could see what limited the unit technician as well as what was frustrating the operators.

8. APPENDIX A – FLOW CHART MAINTENANCE




Back to step 5
Not approved
Unit technician
Operators
Third parties
6. Check maintenance work
approved
Operators
7. Operationalize equipment
Sign of on LOTO lists
Operators
8. Test equipment
9. Rinse equipment
Operators
10. Check equipment for leaks
11. quality control
Unit technician
Operators
13. Operationalize equipment
12. Restore, back to step 1
14. Evaluate maintenance
Process documentation in API Pro
End
Evaluation form

9. APPENDIX B - FLOW CHART SCHEDULING FOR MAINTENANCE



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