Introducing maintenance performance management at dairy producer X

Managing the adaptation of preventive maintenance for the maintenance department

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Management Summary

This report contains research for dairy company X, which produces a variety of dairy products across three manufacturing locations. Each location has a maintenance department, all supervised by a single maintenance manager. During the expansion of company X, the development of a maintenance policy was neglected. This has led to a situation where engineers order parts by themselves, parts are not being processed correctly, and preventive maintenance tasks are not carried out. Order costs, introduced for small orders by suppliers, affected the budget of the maintenance department significantly. After this development, the maintenance manager sought to regain control over the cost and performance of the maintenance department.

The goal of this research is to implement a preventive maintenance approach at the maintenance department of company X, while providing the maintenance manager control over this implementation by using performance management. This corresponds to the following research question:

How can performance management contribute to the implementation of a preventive maintenance policy at the technical department of company X?

By interviewing stakeholders and shadowing the maintenance department, the current situation is analyzed. The enterprise resource system of company X contains promising features that support preventive maintenance but is used as a messenger service instead. Engineers are frustrated by poorly described malfunctions and are disrupted multiple times each day by delivery vans. Spare parts are missing or are defect due to a lack of maintenance, leading to extended breakdowns and high rush order costs.

After completing the literature study, the decision was made to use total productive maintenance (TPM) as the preventive maintenance approach. Spare parts management is outsourced by using vendor-managed inventory.

To implement total productive maintenance, cooperation between departments and total productive maintenance roles are introduced at company X. The production team is responsible for creating a standardized notification when an anomaly is discovered. Each potential work order follows the work order protocol, displayed in figure 0.1, each step eliminates waste in the process. Using this protocol, data is gathered to continuously improve the performance of the maintenance department.

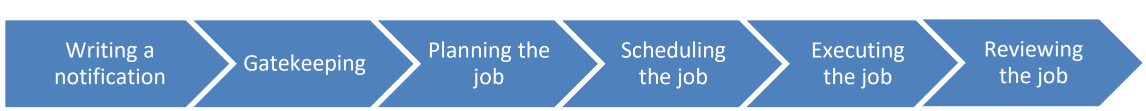

Figure 0.1: The work order protocol

During the literature study, a framework was created for the introduction of performance management at company X. The strategy of company X was translated into objectives for the implementation of total productive maintenance. The TPM implementation grid for company X, presented in table 0.1, contains the key performance indicators that are selected that monitor the process on each objective. The key performance indicators displayed in the TPM implementation grid are used as input values for the periodic review meetings with the various stakeholders. The indicator levels suggest which KPIs are relevant for the various meetings, where KPIs of level 1, 2, and 3 are relevant for higher management, the maintenance manager, and the engineers respectively.

Table 0.1: TPM implementation grid for company X

Objective / Indicator level	Level 1: Production plant	Level 2: Production line	Level 3: Asset
Gain insight in the maintenance expenses		A1	A2
Make the transition to preventive maintenance		B1	
Teach the production team to fulfill their maintenance responsibilities			C1 C2 C3
Develop affinity with the work methods associated with TPM		D1 D2 D3	D4
Prevent accidents by using the work order protocol	E2		E1
Monitor the implementation of TPM	F1	F2	F3

A1) Relative amount of miscellaneous costs
A2) Correctness of notifications
B1) Portion of preventive maintenance jobs
C1) Percentage of notifications the first-time right
C2) # of notifications submitted for jobs that are considered basic maintenance
C3) # of jobs communicated without the use of notifications
D1) Ratio of planned work
D2) Job plan availability
D3) Job plan correctness
D4) Wrench time
E1) # of times a jobsite is not prepared correctly
E2) # of (potential) injuries
F1) Overall equipment effectiveness
F2) Service level of vendor managed inventory
F3) Work order discipline

To conclude, this report contains suggestions on how the maintenance manager can introduce total productive maintenance, vendor-managed inventory, and the work order protocol into the maintenance department at company X. This implementation can be managed by monitoring and reviewing the key performance indicators that are presented in the TPM implementation grid.

Further recommendations are:

- Gaining the support from the stakeholders for TPM by showing its effect through playing a serious game.
- Utilizing the provided methods to add KPIs after the implementation phase.
- Further research on purchasing and warehousing policies, the implementation of Lean maintenance, and a prioritization matrix.

Acknowledgements

This report is the final step in completing my bachelor Industrial Engineering and Management at the University of Twente. My years as a bachelor student can best be described as turbulent and chaotic, and the events around this research match that description.

I would like to thank the people of the company used to base company X on, for their support during the research. I appreciate the time and energy they invested in providing me with the necessary information.

I am grateful for the guidance of my first supervisor at the University of Twente, Peter Schuur. He supported me with feedback and helpful insights. Since I did not have experience with maintenance management prior to this research, almost every meeting was insightful. Additionally, I thank Ipek Seyran-Topan, for being my secondary supervisor and providing me with new insights and constructive feedback on my thesis. I also thank my councilor, Cornelis ten Napel, for helping me find clarity in times of trouble during my bachelor.

Finally, I would like to thank my family and friends for the support throughout my bachelor. Despite multiple setbacks, I could always count on their support. Special thanks to my father for his support during the research, to my study friends for their insights, and to my girlfriend for her unconditional support during tough periods.

Kind regards,

Michiel Jongejan

Hengelo, August 2021

Abbreviations and definitions

ERP	Enterprise Resource Planning	First introduced in section 1.2
CMC	Change Management Commission	First introduced in section 2.2.4
KPI	Key performance indicator	First introduced in section 2.3.3
TPM	Total productive maintenance	First introduced in section 3.1.2
MRO spares	Maintenance, repair, and operating spares	First introduced in section 3.2.1
ROP	Reorder point	First introduced in section 3.2.2
ROQ	Reorder Quantity	First introduced in section 3.2.2
VMI	Vendor-managed inventory	First introduced in section 3.2.2

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1. Introduction

This chapter contains an overview of the research done for completion of the Bachelor Industrial Engineering and Management at the University of Twente. This research is conducted for company X, which is introduced in section 1.1. In section 1.2, the necessity of the research is explained followed by the research design described in section 1.3.

1.1 Company X

Company X was founded after some local dairy farmers decided to produce regional dairy products by themselves. Making a successful start by producing yoghurt, they soon expanded their production to contain a wider variety of dairy products, including long-life milk and desserts. To realize this expansion, company X decided to move the production to three manufacturing locations, each with their own specialty. Apart from having their own production lines, each location has their own technical department and their own engineers.

1.2 Problem description

After the expansion company X stayed ambitious, ideas led to new projects and investments. While the revenue increased, the workload of the technical department increased as well. The engineers are needed for the installation and finetuning of the new machines, while also being responsible for the maintenance of the current machinery. The engineers perceive a high workload, with examples of perceived time wasters displayed in figure 1.1. The development of a maintenance policy was neglected, and no time was taken to reflect on the decisions made.

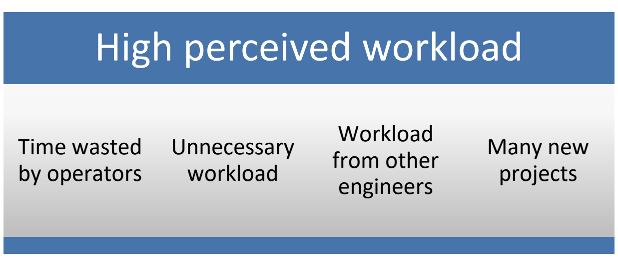


Figure 1.1: No time for data collection?

Currently, there is no policy for the purchasing and warehousing of spare parts for the technical department. This has led to a work environment in which an engineer orders a part by themselves from a supplier of their own choice, without recording which part they have ordered. Thence, the current inventory of the warehouse is unknown, and no maintenance is being conducted on the spare parts. As a result, the engineers miss out on crucial parts during a breakdown, leading to high-cost rush orders, lost revenue, and waste of product. The lack of data increases the risk of a breakdown, since required investments or replacements of failing machinery will not be detected if there is no recorded history. Figure 1.2 contains an overview of problem causes that are further analyzed in Chapter 2, where the current situation is discussed.

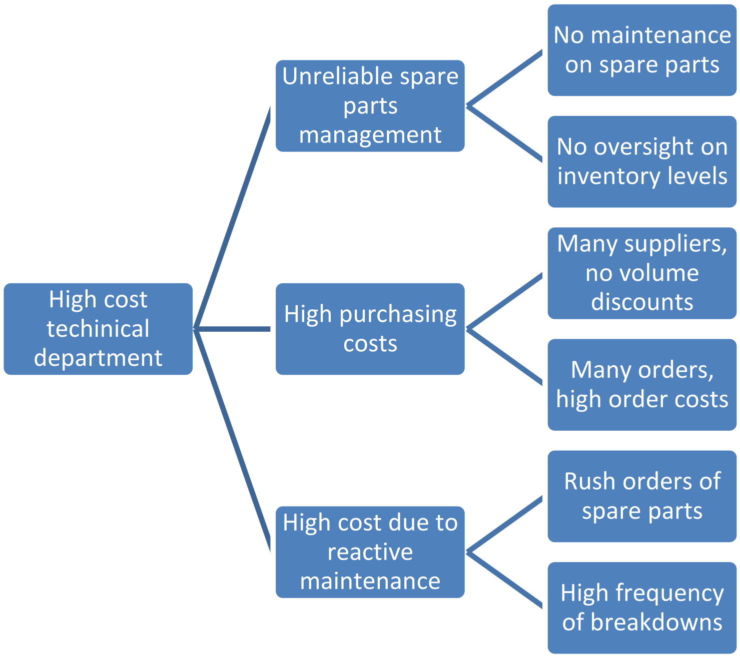


Figure 1.2: Simplistic overview of problem causes

A turning point has occurred, as many suppliers charge order costs for small orders. As stated, most of the orders that are currently being placed will be considered small. To capitalize on the opportunity for change, the manager of the technical department wants to adopt a preventive maintenance policy.

An overhaul of the maintenance policy might be needed to improve the maintenance department of company X. Collecting and using data will be crucial during this process, especially when using performance management to gain control over the performance of the technical department and the machinery. The technical department has access to the enterprise resource planning system (ERP), yet it is widely misused. Instead of utilizing the features, it is used as a messenger service, if used at all.

1.3 Research design

This section covers the structure of the research. In section 1.3.1, the research question is formed. The scope of the research is the topic of section 1.3.2. The research approach, covered in section 1.3.3, contains the questions that support the conclusion on the research question.

1.3.1 Research Problem

Based on the problems encountered during the problem description, and further described in chapter 2, an improved maintenance policy is the way forward. Unfortunately, this will not be as simple as it sounds. Changing policy will impact the way engineers do their jobs, so their approval and support throughout this process is crucial. Showing data that supports the theory can help convince engineers that the result is worth the effort. The main reason to collect data,

as mentioned, is to gain control over the costs and performance of machinery and the processes within the technical department.
This leads to the following research question:

How can performance management contribute to the implementation of a preventive maintenance policy at the technical department of company X?

1.3.2 Scope of research

The main goals of this report are:

i) Giving company X insight in preventive maintenance management
ii) Recommending policies that support preventive management
iii) Introducing performance management to monitor the implementation of preventive maintenance

Since the research will be conducted in ten weeks, it will not be possible to make a layout of the warehouse with current inventory levels, nor will it be feasible to list the machinery including parts in the ERP system. While this report mainly focusses on the technical department, other departments can, directly or indirectly, be affected. While conducting preliminary research, best practices suggested some co-operation between departments is desirable. This report does not provide an in-depth analysis on how all the other departments can be affected by this transition. Naturally, solving the problems of the technical department by passing them on to other departments is not the purpose of this research.

1.3.3 Research Approach

The research question can be answered by addressing the following steps and sub-questions. Each step corresponds with a chapter in this report.

Chapter 2 contains an in-depth analysis of the current situation of the technical department. The structure of the technical department is described, the responsibilities and way of working included. Subsequently, the ERP system is the topic of investigation. The current procedures regarding purchasing and warehousing are discussed. These topics answers the following sub-questions:

1. *What is the structure of the technical department?*
2. *How is the ERP-system utilized by the technical department?*
3. *What procedures are currently in place at the technical department?*

These sub-questions are answered by conducting interviews and inspecting both maintenance protocols and the ERP-system.

Chapter 3 contains the literature study that answer the following sub-questions:

4. *Which maintenance management approach has the most potential for company X?*

5. *How can the maintenance policies be designed to support this approach?*
6. *How can performance management be used in maintenance management?*

The answers found during the literature study are the foundation on which both chapter 4 and chapter 5 are built. The transition to a preventive maintenance approach has consequences for the maintenance department. Chapter 4 describes how the maintenance approach and corresponding policies found in the literature study affect the structure and work method of the maintenance department at company X, by answering the following sub-questions:

7. *How does the transition to preventive maintenance affect the structure of the maintenance department?*
8. *How can the maintenance policies found in the literature study be implemented in the maintenance plan?*

Making a transition to a preventive maintenance approach is likely to affect various aspects of maintenance management. To manage this transition, performance management is introduced in chapter 5 with the following sub-question:

9. *How can performance management be used to monitor the transition to preventive maintenance at the maintenance department of company X?*

Lastly, the conclusion that aims to answer the research question formed in section 1.3.1 is the topic of chapter 6, along with a discussion and recommendations.

2. Current situation

The problem description in section 1.2 contains a preview of the current situation of the technical department. This chapter provides an in-depth analysis on the way the technical department functions as of this moment. A general description of the structure of the technical department is provided in section 2.1. Section 2.2 examines the ERP-system used by company X. An analysis on the current purchasing and warehousing procedures is the topic of section 2.3. Section 2.4 contains the conclusion, in which the research questions corresponding to the current situation are answered.

2.1 Technical department

To gain understanding of the current work methods of the technical department, an analysis of the structure is presented in this section. Section 2.1.1 contains the organizational chart with the members of the technical department. Section 2.1.2 clarifies the responsibilities of the department. The roles of the engineer, planner, and manager are explained in sections 2.1.3, 2.1.4, and 2.1.5 respectively. The workshops of the locations and the co-operation between the locations are the topic of sections 2.16 and 2.1.7

2.1.1 Structure technical department

Company X has three production locations within proximity of each other. Because each location has their own technical department, they also have their own engineers. Each engineer has a specialty: either mechanical or electrical engineering. Since the size of each factory varies, so does the distribution of engineers. The distribution of the engineers is displayed in the organizational chart (figure 2.1).

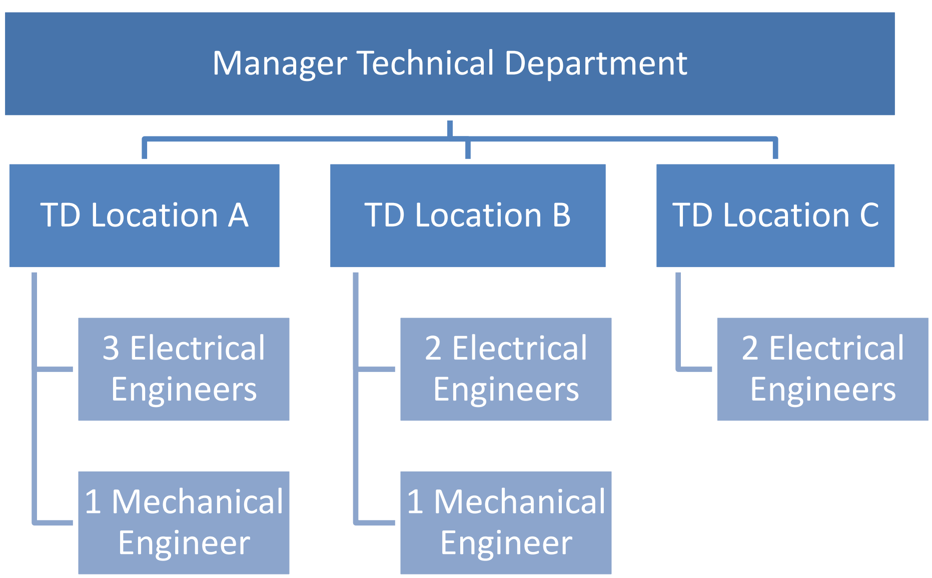


Figure 2.1: Organization chart Technical Department

As shown in the organization chart, the technical department of location C lacks a mechanical engineer. Whenever an error occurs that requires a mechanical engineer, the other locations are informed, and a mechanical engineer will make his way to location C.

2.1.2 Responsibilities

In short, the technical department is responsible for the maintenance of the machinery of company X. This means that the technical department must resolve breakdowns or prevent breakdowns by taking preventive measurements. Company X expects the engineers to improve production lines when possible. The technical department has a crucial role in the implementation of new machinery, as these machines need to be fine-tuned by the engineers.

2.1.3 Engineers

Currently, company X has employed seven electrical engineers and two mechanical engineers. Electrical engineers are specialized in electrical systems, thus crucial for maintaining and adjusting the machines. The mechanical engineers are specialized in the maintenance of the moving parts of the machinery, so they lubricate gears and replace worn components for example. Apart from their responsibilities as mentioned in section 2.1.2, the engineers are also buying and storing spare parts.

The following narrative is included with the purpose to illustrate the effects of the current maintenance situation. In this narrative, an average workday of an engineer is described. For privacy reasons, the narrative is fictionalized. However, all events described occurred in during the period of the research.

Introducing Joe, a 23-year-old electrical engineer. After graduation, Joe was employed by the company to work the morning shift. Joe never doubted his decision to work as an electrical engineer, since he spends his weekends tuning his car. He loves the challenge of improving processes by making modifications, and fixing broken equipment gives him great satisfaction. Despite the seemingly perfect match, his job satisfaction level declines during the day.

The shift starts at 7:00 AM, Joe enters the workshop to find a gathering of spare parts. His coworker, Steve, rushes in behind him. "Morning Joe! Sorry for the mess, I just repaired the drainage system at line 2. It took me a fair amount of time before I found the flaw. It should be running smoothly now. I will tidy this up before I leave! How is the modification coming along on the sorter? Remember, they want to install it next week."

Ah yes, the sorter, Joe thought. The manager had told him to improve the rotational speed of the machine in order to increase production. Assisted by a cup of coffee and his wrench he started working. 8:15, Joe's concentration was suddenly disturbed by the noise of his mobile phone. The foreman of the production team tells Joe to come over to production line 2, without giving any information. Joe drops his tools, disinfects his hands and outfit according *to the guidelines, and enters the production hall. Upon arriving, the foreman points to a loose bolt. Joe tightens the bolt, while being frustrated with the fact that the foreman could do this himself, instead of calling him over. Back at the workshop he resumes his task. Half an hour later, the manager walks in and ask Joe to come to the office. The marketing department has come up with a new idea, they want smaller cups for the yoghurt. They want to test a new batch within two weeks, so all machines must be adjusted by then. The rest of the morning is spent listing all machines and parts that have to be adjusted and discussing the methods necessary for this.*

Finally, Joe is working on the sorter again. Not for long though, as the same foreman calls again. To prevent frustration, Joe asks if it is the same problem. This time however, product is leaking out of the machine, and now there is a breakdown. To find out what the problem is, Joe inspects the machine to find that an engine has failed. Joe returns at the workshop in search of a spare engine, after a couple of minutes he finds a fitting engine. To his surprise, this engine is also broken, apparently due to a lack of maintenance. Joe places a rush order and returns to the production hall. To prevent a complete production stop, he uses an engine with less power as a temporary solution. Back at the workshop, a supplier has arrived for some parts a coworker has ordered. Because of this distraction, Joe does not make a notification about the temporary solution. Joe finishes his shift trying to finish the modification.

The rush order arrives the next shift, the engineer is not aware of the importance of this engine. He puts the engine away, while the engine inside the machine caused another breakdown later that week.

2.1.4 Planner

In addition to being an engineer, one of the electrical engineers of location A combines his function with a new function, the planner. The planner receives the incoming notifications and distributes them towards the available engineer. The production planning is also forwarded to the planner to search out the possible time frames to install modifications on the production line. The planner is tasked with the administration of finished jobs in the ERP system. Each morning, the planner must attend the meeting between the production, planning, and technical department to hear what is expected from the engineers during the day. This combination between roles has not been ideal. The other locations do not have a planner in the current situation.

2.1.5 Manager technical department

The manager of the technical department arranges the overarching matters of the technical departments of the three locations. The manager is responsible for the improvement of the work methods used by the engineers. By attending conferences, the manager is finding new ways to improve the production process. For each improvement, it is necessary to submit a request for improvement. The manager is responsible for this process, described in chapter 2.2.3. The manager maintains the relationships with external parties and internally acts as point of contact for matters concerning the TD. External parties include, but are not limited to, existing suppliers looking for increased sales, new suppliers looking for a customer, and consultancy firms looking to sell their expertise. In the current situation, a not insignificant portion of his time is spent handling invoices and matching them to the right budget.

2.1.6 Workshop

On each of the three locations, a space is assigned to the technical department. These are located just outside the production halls, and engineers must disinfect themselves every time they go inside the halls for hygienic reasons.

While varying in size, each workshop has room for:

- A spare part warehouse, located on the floor above the workshop
- A desk with at least one computer, to order spare parts and utilize the ERP-system
- A working desk with the appropriate tools for the engineers
- The archive, on paper and digital, consisting of manuals, layouts, and technical references for the machinery.
- Locations A and B have special equipment for the mechanical engineers.

An example of a workshop is presented in figure 2.2. The example presents a workshop on the left side, and a spare part warehouse on the right side.

Figure 2.2: Example of workshop (RMN, 2016)

2.1.7 Cooperation between locations

The desire for cooperation between locations has been expressed by the technical department. As mentioned before, the mechanical engineers from locations A and B carry out assignments for location C when necessary. The electrical engineers are only shared following sickness or leave of absence. Since the three locations produce different dairy products, the machinery differs as well, causing problems for substitute engineers. Despite having different machinery, spare parts may overlap. Currently, engineers are placing rush orders, while the desired part may be sitting on a shelf at another location.

2.2 ERP system

Company X has access to a comprehensive enterprise resource planning system, including a module specialized on maintenance management. Currently, the use of the system is reduced to the ‘Job’ discipline. The job discipline is the topic of section 2.2.1, while section 2.2.2 contains the method corresponding to each job. A description of the way notifications are currently written is presented in section 2.2.3. A job can become a modification, this process follows the modification procedure, which is explained in section 2.2.4.

2.2.1 Jobs

All users of the ERP system can create a job, or work order, for the maintenance department. A job belongs to one of the following maintenance classifications:

- Modifications
- Preventive maintenance
- Projects
- Repairs
- Revisions
- Breakdowns
- Inspections

Proposed jobs are automatically placed on a to-do list. Currently, there is no priority attached to the jobs on the to-do list, so engineers pick a task subjectively. Engineers inform the manager when they suspect a job to be expensive or to have an impact on production. Engineers have the authority to decline proposed jobs, they are encouraged to do so if crucial information is missing on the job description. After finishing, the engineers send the job to the manager for approval. The initiator that created the job receives feedback if the engineer declines the proposed job, or if the manager approves the finished product.

2.2.2 Job method

Each maintenance classification has a specific work method. Projects, modifications, and revisions are discussed in a meeting, since they have a large impact on the production capacity. Preventive maintenance jobs, lubrication routes for example, can be generated by the ERP system and need to be scheduled. Repairs and inspections are mostly done during the lubrication routes and can be conducted by a single engineer. Currently, breakdowns are not reported by the ERP system, but by phone.

Modifications are changes in the design of a machine or process. In the narrative of Joe, in section 2.1.3, improving the rotational speed was an example of a modification. The idea of the marketing department, however, to change the size of the yoghurt cups, is a project since multiple modifications must be made in the entire production line.

Repairs are jobs concerning undesirable situations that do not pose a threat to the production process at this moment but might if the problem is ignored for too long. For example, a cracked window does not interrupt the production process. If this window is not replaced, however, the glass may break and cause a stop in production.

When a machine cannot be used for a long time due to an overhaul, the job is a revision. Some malfunctions can be specific and may require help from specialized engineers. This can cause machines to be out of production for an extended amount of time.

Breakdowns have a direct impact on the production process. Whenever a breakdown occurs the production is halted, and the production team has a paid break. Extended breakdowns also disrupt the production schedule and can threaten obligations to customers. To inform the engineers as soon as possible, the breakdowns are reported by phone. The breakdowns are supposed to be registered in the ERP system afterwards, but in practice they are registered on a paper sheet instead.

2.2.3 Notifications

While the maintenance department sees the unutilized functions of the ERP system as a potential improvement, the current utilization has room for improvement as well. Vague and incomplete notifications are not being filtered correctly, and a significant amount of time of the engineers is wasted because of it. What needs to be included in a good notification is discussed in Chapter 3. Currently, the notifications that cause frustration are written in the following structure:

> Hi, there is some yoghurt on the floor, please come check it out.
>
> Sender: Sven

In this case, an engineer should not accept the job, and Sven should receive feedback on this poor notification. Lost product can be an indication that a breakdown will occur or has occurred, so the engineer calls Sven to receive more information. Sven does not answer, so the engineer must now locate Sven, investigate the machine to find the malfunction and return to the workshop to get the tools and spare parts. Currently, notifications that describe the problem to such an extent that the engineer knows what tools to bring are rare.

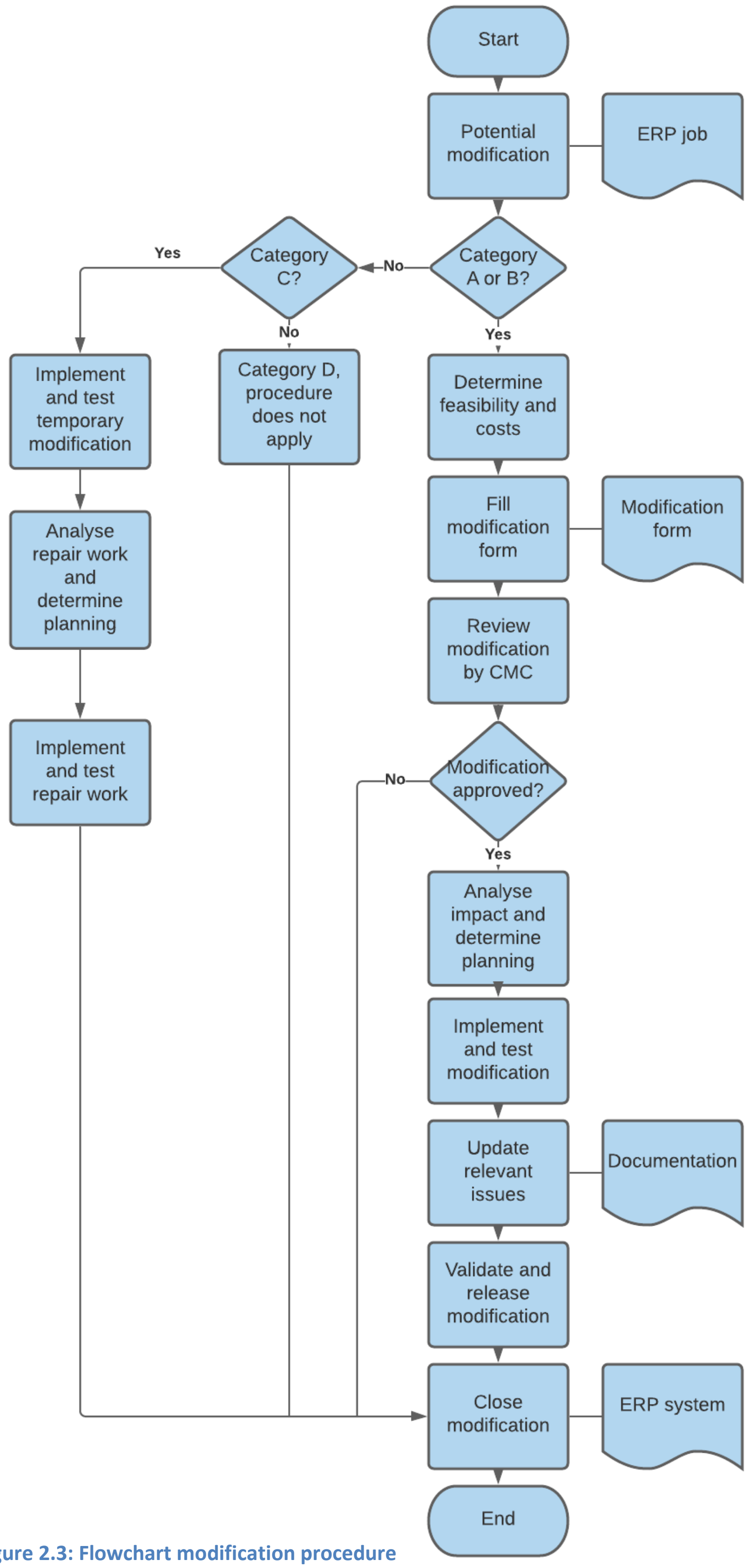
2.2.4 Procedure modification

In the production facility, standards concerning safety, quality, ecological, and legal standards must be maintained. While modifying processes, installations or machinery, these standards should be considered. For this reason, a protocol has been installed with a Change Management Commission, abbreviated to CMC. The CMC members are the managers from the production and technical department, the head of quality control and the director of operations. An important note to make, the term ‘modifications’ in the CMC context is used for all jobs, including revisions, repairs and projects. Each modification belongs to one of the categories displayed in table 2.1.

Table 2.1: Type of modifications

Category	Type of modification	Explanation
A	Permanent modification	Permanent modifications on machinery, each project is a permanent modification for example.
B	Technical upgrade	Small technical adjustments or upgrades on machinery, a small or singular modification job can be considered an upgrade.
C	Temporary replacement	Temporary replacement with the goal to return to original situation. Can be placed to quickly resolve a breakdown.
D	Replacement	A new part has an identical function and suffices in the design specifications.

These categories are used in the flowchart below, figure 2.3, made by company X, to illustrate how the procedure works.



Initiator creates job in ERP system.

Initiator selects classification.

Initiator fills in the modification form and hands in the form to the CMC.

Initiator is informed of decision.

Initiator and relevant departments handle the points of attention, such as required training for staff.

The documentation is updated, and the form, invoices and other relevant papers bundled.

Figure 2.3: Flowchart modification procedure

2.3 Procedures

In addition to the work methods used by the engineers to complete maintenance jobs, procedures have formed for the other responsibilities of the maintenance department. After interviewing the stakeholders, three procedures are analyzed in this section. The procedure regarding the purchasing of spare parts is the topic of section 2.3.1. The procedure concerning the warehouse is the topic of section 2.3.2. The key performance indicators that are being used are analyzed in section 2.3.3.

2.3.1 Purchasing procedure

In the current situation, an engineer orders a new spare part directly after using the part in a job, thus maintaining the inventory levels in the warehouse. Each engineer has their own preferred supplier, from which website they order the part. The parts are received by the engineers at the workshop, causing deliveries to interrupt the work of engineers in the workshop. Since engineers are placing orders directly and at different suppliers, the number of deliveries, and therefore interruptions, is considered excessive.

The distraction of engineers is not the sole reason for adapting a new policy for the technical department: the costs of the current situation are on the rise. For years, most suppliers delivered parts without order costs, small orders included. These small orders were delivered, despite not being profitable, as a form of customer service. Unfortunately for company X, they are not considered a core customer anymore, so this service is dropped by their suppliers. This decision is a consequence of having a high number of suppliers. Internal documents show emails in which company X is imposed to pay order- and delivery costs.

Steel pipes are not delivered by a normal delivery van. The supplier of steel pipes charges €50 delivery cost for orders smaller than €300. If the order is smaller than €150, €25 administration costs is charged, even if the order is picked up by company X. In the current situation, in which each engineer places an order immediately, these costs can add up quickly. Hypothetical, four engineers place orders for steel pipes, each order costing around €80. In the current situation, for each order, €75 order- and delivery costs are charged. If the engineers decided to bundle their orders, the combined order has a value above the €300.
Current situation: 4 x (80+75) = €620
Combined purchasing: 4 x 80 = €320
While this situation is not likely to occur, it illustrates the cost of the current procedure.

Another downside of having a high number of suppliers is missing out on volume discounts. Most suppliers of company X work with a total yearly volume discount as shown in figure 2.4. These discounts can add up quickly and are used by the suppliers as an incentive for companies.

Volume (x1000)	Discount
€50-€100	1%
€100-€200	2%
€200-€300	4%
€300-€500	8%
€500+	Company approached with special offer

Figure 2.4: Example of stacking discounts

The manager of the technical department processes the invoices that result from the current situation. Instead of spending time on improving the department, the time is used up on this administrative task.

2.3.2 Warehousing procedure

The lack of communication in the current purchasing procedure results in ambiguity when it comes to the warehousing of spare parts. Each spare part that is received could either be ordered to maintain the inventory level or was order with the intention to be implemented in the production line as soon as possible. Unless the engineer placed this order himself, the receiving engineer does not know the purpose of the order. Since the work of the engineer was suddenly interrupted by the delivery, the engineer wants to return to his work. So, he places the spare part in the warehouse on a place logical to him and returns to work.

<table>
<tr><td rowspan="2">Frequently used, small spare parts (Bolts, seals, etc)</td><td>Stairs to workshop</td><td>Frequently used, large parts (Tubes, cords, etc)</td></tr>
<tr><td>Electrical parts</td><td>Miscellaneous</td></tr>
</table>

Figure 2.5: Layout of the warehouse at location A

The warehouses of the three locations differ in layout, but the challenges are similar. The layout in figure 2.5 describes the warehouse of location A. While there is no designated place for a specific part, the warehouse is roughly divided in four categories. Since there is no clear description of each category, it is possible for a part to end up on multiple locations. For example, a screw terminal (Dutch: kroonsteentje) is both a frequently used, small spare part but can also be placed on a shelf for electrical parts due to its function. Since each engineer uses his own logic for the placement of a part, the warehouse is disorganized. Because of this, it can be a quest to collect a spare part, causing delays in repairs.

It is also possible for an engineer to search the warehouse, only to find out the part is missing entirely. This can happen if an engineer forgets to order a part after using one, or if the parts are being used at a rate that surpasses the delivery rate for that part. When this happens during a breakdown, a rush order is placed. A rush order is an expensive solution since the supplier normally charges more for a rush order. In addition, the part is rushed over, thus will not be included in the delivery routes of the supplier. Depending on the location of the supplier, the transport costs can add up quickly. During this time, company X may not be able to produce certain products or use a certain production line. This results in loss of revenue, waste of product and waste of labor.

To gain control of the inventory levels in the warehouse, one engineer created a spreadsheet for all engineers to write down incoming and outgoing spare parts. The sheet contained the type of spare part, the inventory level after placing or removing a spare part, and location of the spare part in the warehouse. In this spreadsheet, the warehouse is treated as a black box, there is no knowledge on what, or how many, parts are currently in the warehouse. By controlling the input and output, missing out on parts could be prevented, and eventually all parts could be counted and written down in the sheet. Unfortunately, some engineers were not convinced this idea was worth the time and chose not to participate, preventing the sheet from being updated accurately. After a few weeks, the other engineers lost their motivation, and the sheet was neglected.

Treating the warehouse as a black box is not without risk, since a portion of the spare parts need maintenance, even while being stored in the warehouse. Without this maintenance, the lifetime of the new part can be reduced significantly. Additionally, having overly high inventory levels can be costly, due to holding costs. Having a spreadsheet that includes all parts in the warehouse is also necessary for an insurance company in the case of a fire, for example.

In conclusion, there is not a sound policy in place regarding spare part management. The engineers understand the consequences of the current way of working and have tried, unsuccessfully, to improve the spare part management. The disorganized warehouse, with unregistered and possible broken spare parts, and a lack of spare part management prevent the technical department of gaining insight and control of the costs.

2.3.3 Key performance indicators

While performance management is not utilized by the maintenance department at this moment, the key performance indicator (KPI) is introduced in meetings with members of the production- and maintenance department. Each morning, the manager of the maintenance department, an engineer, the manager of operations, and the foreman of the production team have a meeting to discuss the key performance indicators. The KPIs that are currently in place are:

- Downtime: for each day, how many minutes were lost due to breakdowns?
  Controlled by manager operations
- Breakdown repairs: for each day, how many minutes were spent on breakdown repairs?
  Controlled by engineer
- Planned downtime: for each day, how many minutes were planned for preventive maintenance/projects?
  Controlled by manager technical department
- Waiting time: for each day, how many minutes was the production delayed due to extended preventive maintenance/projects?
  Controlled by foreman

The values of these KPIs are used in the meeting, afterwards the values are wiped out and the whiteboard is used for the following week. When the whiteboard was introduced, different KPIs were used to improve the production process. In a week of frequent breakdowns and corresponding frustrations, a foreman placed the blame for the high downtime on the engineers. The attending engineer was not pleased, and denied the time spent on breakdown repairs. Afterwards, the engineers decided to write down the time of the incoming notification and the time of finishing the repair, to prevent unjustified blame. As expected, the production team was not pleased by this action, and started to time the delay caused by extended preventive maintenance and projects. Other KPIs were dropped, and each department chose KPIs to cover themselves from blame, instead of trying to improve the processes. While the relation between the departments normalized, the KPIs have not changed.

2.4 Conclusion

Chapter 2 contains an overview of the current situation and provides answers to the corresponding research questions presented in section 1.3.3.

What is the structure of the maintenance department?
The maintenance department consists of engineers, who are spread out over three different locations, with the manager of the technical department overlooking the whole department. One location is experimenting with the function of planner. Each location has its own workshop, and the work processes are similar, while the machinery is not. One location does not have a mechanical engineer, so a mechanical engineer is 'borrowed' from the other departments. Apart from this engineer, there is no cooperation between locations.

How is the ERP-system utilized by the maintenance department?
The maintenance department has access to an ERP-system with a maintenance module. Currently, the use is reduced to the job notifications. Notifications are not standardized; this leads to misunderstandings and frustration. The engineers choose their jobs subjectively since a priority system is missing. The only job notifications that are used as intended are the job notifications concerning modifications that are processed by the change management commission.

What procedures are currently in place at the maintenance department?
Lacking the need of placing policies in the maintenance department, procedures have been developed for all aspects of the maintenance department. In the current situation, engineers order by themselves, leading to increasing costs and administration. The ordered parts are delivered at the workshop, disrupting the engineers. The parts are placed somewhere in the warehouse, the content of which is unknown. The key performance indicators that are being used are not focused on improving the production processes but used by each department to cover themselves from blame.

3. Literature study

This chapter contains the literature framework for this research. This literature study provides the answers for the following sub-questions.

- *Which maintenance management approach has the most potential for company X?*
- *How can the maintenance policies be designed to support this approach?*
- *How can performance management be used in maintenance management?*

The different approaches regarding maintenance management are covered in section 3.1, the trade-off between them included. In section 3.2, feasible designs for the maintenance policies at company X are presented. These policies concern the way notifications are written, and the way spare parts are purchased and stored. The use of performance management in maintenance management is the topic of section 3.3. The findings are summarized in section 3.4.

3.1 Maintenance management approaches

Prior to explaining the different approaches to maintenance management, a brief background on maintenance management is provided. The definition of maintenance is: *'The combination of all technical, administrative, and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function.'* (European committee for standardization, 2010).

The cost resulting from maintenance management was considered a necessary evil by higher management, while they ignored the impact on product quality, production cost, and profit (Mobley, 2004). Thus, maintenance was not a priority for research. According to a literature review on maintenance management (Deshmukh & Garg, 2006) most studies on maintenance management were published after 2000. New philosophies emerged, with the arrival of computers at its core. All these approaches can be categorized in three groups: reactive, proactive, and aggressive maintenance management. These approaches are analyzed in sections 3.1.1 through 3.1.3.

3.1.1 Reactive maintenance management

According to *Maintenance Fundamentals* (Mobley, 2004) reactive maintenance management follows the run-to-failure philosophy. This is the oldest maintenance management philosophy, where no money is spent on the machines before they are broken. Although most reactive maintenance plants perform basic preventive tasks, like lubricating the machines, they still wait until a failure occurs before they act. Since there is no preventive maintenance, the maintenance team must react to all sorts of failures. This type of maintenance is considered expensive due to high spare part inventory costs, high overtime labor costs, high downtime, and low production availability.

3.1.2 Proactive maintenance management

Most maintenance approaches are proactive maintenance approaches, also known as preventive maintenance management. While reactive maintenance is *event-driven,* proactive maintenance management is *time-driven* and aims to prevent breakdowns by acting before a failure occurs. The methods to achieve this goal differ. Some plants rely on industry average-life statistics, like the mean time to failure, and replace a part before it is expected to break. Collecting maintenance data for a certain period allows plants to gain insight in the mean time between failures for their own machines, resulting in a better forecast. An advanced proactive maintenance management is predictive maintenance. Plants using this approach use measurements, for example thermography and vibration monitoring, to predict the next breakdown.

A special proactive maintenance approach is total productive maintenance (TPM), which originated in Japan. TPM is designed to maximize equipment effectiveness (improving overall efficiency) by establishing a comprehensive productive-maintenance system covering the entire life of the equipment, spanning all equipment-related fields (planning, use, maintenance, etc.) and, with the participation of all employees from top management down to shop-floor workers, to promote productive maintenance through motivation management or voluntary small-group activities (Tsuchiya, 1992).

Another proactive maintenance approach originating from Japan is lean maintenance. It follows the philosophy of lean manufacturing. Lean Manufacturing is the practice of eliminating waste in every area of production including customer relations (sales, delivery, billing, service, and product satisfaction), product design, supplier networks, production flow, maintenance, engineering, quality assurance and factory management. Its goal is to utilize less human effort, less inventory, less time to respond to customer demand, less time to develop products and less space to produce top quality products in the most efficient and economical manner possible (Smith & Hawkins, 2004). Lean maintenance aims to eliminate waste in the maintenance department. Having excessive inventory levels and sending engineers for a quest due to a bad notification are examples of waste.

3.1.3 Aggressive maintenance management

The last category is aggressive maintenance, an approach that is *reliability-driven*. Instead of preventing a breakdown by scheduling preventive maintenance, modifications are being made in the machine to make it more reliable. Machines can be redesigned, or reordered, to reduce potential failures. In recent years, additive manufacturing (3D printing) has been used to create spare parts or prototypes. Engineers at KLM, for example, use additive manufacturing to design modifications and tools from recycled plastics. (KLM, 2019).

3.1.4 Tradeoff

After reviewing the maintenance approaches, a tradeoff can be made. This tradeoff will include strategic elements proposed by company X.

It is easy to dismiss reactive maintenance, as its downsides caused the evolution of other maintenance approaches. The benefits of reactive maintenance are found on a personal level, the process is very easy to understand: “if it works, do not fix it”. There is no planning required, avoiding difficult negotiations with the production- and planning department. Reactive maintenance leads to uncertainty and frustration, but it also leads to glorification of the engineers. They are the heroes that ‘save’ the production team if a breakdown occurs. Based on multiple interviews with the engineers, they get an adrenaline boost from fixing a problem, more than they get from doing preventive maintenance tasks. As mentioned, there are numerous downsides to reactive maintenance. Foremost, it is a very costly approach due to high spare part inventory costs, high overtime labor costs, high downtime, and low production availability. A lack of maintenance can lead to shorter asset life expectancy, and the chaotic situations occurring during breakdowns can lead to neglection of the safety protocols.

Proactive maintenance management, while having multiple approaches, is used to gain control over the machinery. With preventive maintenance tasks, machines are less like to break down, leading to an increased lifetime of assets. Machines are more reliable, with low machine downtime and plannable repairs. While all proactive maintenance management strategies have startup costs, it is cheaper in the long run compared to reactive maintenance. Motivation of the employees is crucial since discipline is needed for proactive maintenance.

Aggressive maintenance is not feasible as an approach on its own since certain machines cannot be modified. It can be cost-effective to find alternatives for the parts that tend to break often, so aggressive maintenance policies can be added to proactive maintenance.

For company X, proactive maintenance management is the most logical approach since reactive maintenance management is becoming too expensive and unreliable. As mentioned, there are multiple strategies within proactive maintenance. A point could be made for a total overhaul of the whole plant, with machinery equipped with vibration sensors and 3D printers in the workshop. The maintenance department does not have the means for such an overhaul. Additionally, multiple engineers are afraid of a hard shift in policy. They are willing to adapt, if they understand how it is going to contribute to their way of working. This might be a cultural mindset, in this region they call it ‘Boerenverstand’, which translate to a form of common sense. Without being condescending, hi-tech solutions like using 3D printers to get spare parts will be considered a luxury, and not a necessity by these engineers.

The fear of a hard shift in policy is justified if company X adapted lean maintenance. Lean maintenance is considered an upgrade over TPM. According to *lean maintenance* (Smith & Hawkins, 2004), implementing lean maintenance without total productive maintenance can be compared to laying bricks to build a house before the foundation is placed. Implementing TPM and lean maintenance simultaneously is compared to preparing for the super bowl while recruiting the football team. If a maintenance team is more familiar with TPM, and data has been collected for an extended time, lean maintenance can be focused on the activity with the highest waste. For company X, this is not the case.

Total productive maintenance, however, can be implemented without losing support of the maintenance department. While TPM demands discipline from the engineers for accurate data gathering, the engineers will be relieved from some tasks they experience as annoying. By sharing the responsibility of the machines with the operators, trips to the production facility to tighten a single bolt will be reduced, as will unnecessary investigations that are caused by incomplete notifications as described in 2.2.3. TPM can help to continuously improve the maintenance department, by using the gathered data to predict the materials and time needed for a repair. Improving those predictions helps the engineers by gaining wrench time, the time an engineer is working on the required job with his tools, by reducing time spent gathering materials and tools and the time spent traveling to do so. Generally speaking, engineers enjoy their wrench time more than they enjoy the tasks that are necessary to start working on the required job, the non-wrench time. Higher wrench time leads to an increased productivity, as less time is wasted each job. Better predictions also help the operations department, jobs can be scheduled with less uncertainty, reducing the time an operation team is waiting on an engineer to finish to start their shift.

To conclude, total productive maintenance has the potential to improve the output of the maintenance department at company X while gaining control over the maintenance budget. With a smooth implementation, TPM can get, and keep, the engineers motivated to adapt to the new policies.

3.2 Maintenance policies

To achieve a smooth transition and prevent the loss of support from the involved employees, an update of the maintenance policies is necessary. Derived from section 2.3, an updated policy regarding the purchasing and warehousing of spare parts is required. Section 3.2.1 focusses on a policy regarding the management of spare parts. Section 3.2.2 contains a corresponding purchasing policy. As mentioned, data collection is crucial for long term improvements at company X. Therefore, section 3.2.3 presents a standardized notification for company X to use.

3.2.1 Management of spare parts

This report does not aim to present an optimized spare parts management solution. However, the purpose of this section is to present a spare parts management solution that is feasible for total productive maintenance at company X.

The management of spare parts can lead to significant costs if done poorly. As mentioned in chapter 2.3.2, missing out on a spare part means rush orders, idle employees, and a loss in production. On the other hand, having a surplus of inventory is costly too. The money invested in obsolete spare parts cannot be used to generate revenue. Maintenance parts are not being purchased for resale, meaning these parts only return their investment when they are being used.

Finding this balance is complex, most technical departments have a vast number of spare parts, company X included. Due to this number and the variety of parts, the categorization of spare parts is a way of controlling their diversity and specificity (Molenaers, Baets, Pintelon, & Waeyenbergh, 2012). Without categorization, a company either has a single policy regarding all spare parts, like company X, or tries to have a policy for each spare part, adding complexity to spare part management. Common spare parts that have low value and are used frequently, like nuts and bolts, should be managed differently in comparison to an expensive spare engine that is crucial for a production line.

By differentiating and grouping spare parts to define the most appropriate stock management policy for each group, spare parts can be placed in one of four categories (Teixeira, Lopes, & Figueiredo, 2018). The four categories used in this article are A, B, C, and D, in decreasing order of criticality. The criticality of a spare part can be found in the combination matrix (figure 3.1).

The score on *function* is determined by the function of a spare part in the production process, where a score of 1 is given if the spare part does not interfere with the production process directly. A score of 2 is given if the function of the spare part relates to the safety of operators. A score of 3 is given if the part is used in the primary function of the equipment.

The effect of failure of the spare part determines the *production impact score*. No effect on production corresponds to a score of 0, loss of quality to a score of 1, reduction of production to a score of 2 and a stop in production to a score of 3.

		Production Impact			
		0	1	2	3
Function	1	1	2	3	-
	2	2	-	4	5
	3	-	4	5	6

Desirable
Essential
Vital

Figure 3.1: combination matrix

Additionally, the lead time, price, and the annual consumption of the spare part are considered to assign a spare part into a category. The weight of each criterion depends on the company. Generally, a desirable, non-frequently used, spare part that has same-day shipping and a low price can be placed in category D. Vital spare parts with high lead time are likely to be placed in category A. For each category, a corresponding policy is presented.

Category D: Parts are consciously not being stored at the warehouse.
Category C: One spare part is stored, reorder the part after usage.
Category B: Reorder point and reorder quantity are calculated, with minimum safety stock.
Category A: Reorder point and reorder quantity are calculated, with appropriate safety stock.

The categorization at company X can be determined by the multi criteria analysis. A point could be made to deviate from the *function* criteria used by this paper, since the safety of operators could be considered crucial.

Maintenance, repair, and operating spare parts (MRO spares), like bolts and nuts, that are relatively cheap and are used frequently are not eligible for this system. It is not efficient to calculate a reorder point for each type of MRO spare, since the count of MRO spares is easily lost. According to "Smart Inventory Solutions" (Slather, 2010), a Kanban system can be set up. For most MRO spares, this will lead to a 2-bin system, displayed in figure 3.2. After emptying the first bin, another bin will be ordered, while the second bin becomes the first bin. Since this system uses storage buffers, it is not considered to be lean. However, the space and value of potentially unused bins is limited, thus, it is considered a feasible solution.

Figure 3.2: MRO 2-bin system

The storeroom in which these spare parts are held is crucial for spare parts management. A storeroom can impact outcomes negatively if it is poorly laid out or poorly labeled, making it difficult to find items. The layout of a storeroom should work for the engineers since they need to retrieve parts quick and easy. Stored parts should be protected from environmental effects, and the catalogue should be kept up to date by conducting counts (Slather, 2010).

3.2.2. Purchasing of spare parts

This section aims to find a purchasing policy that supports the spare part management policy described in section 3.2.1. As mentioned in section 2.3.1, the engineers of company X are placing orders at multiple suppliers. Having multiple suppliers is inevitable since specialized parts are only available at certain suppliers. For company X, the array of 'general' suppliers is a challenge. This report does not provide an optimal supplier selection for the different spare parts. From this point, the assumption is made that it is feasible for company X to have a single 'general' supplier, to maximize the volume discount. In case a part is not available at this supplier, company X will use another supplier without this discount.

The categories mentioned in section 3.2.1 provide a corresponding order strategy for each category. The reorder point and reorder quantity can be explained with figure 3.3. The quantity at hand decreases over time, as parts are being used by the engineers. The reorder point can be calculated to prevent stockouts. Unfortunately, the demand (usage of a part) is usual not linear, hence the safety stock. For slow moving spare parts, there will likely be insufficient data to use a normal distribution to determine the demand. For this reason, the Poisson distribution is used to determine the probability of the exact number of the demand during the lead time (Slather, 2010).

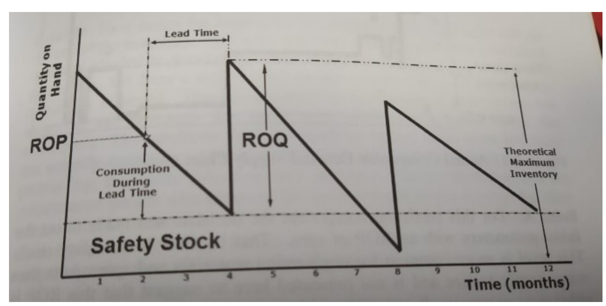


Figure 3.3: Graph of inventory position over time, illustrating the ROP and ROQ (Slater, 2010, p. 17)

To calculate the reorder point (ROP) and the safety stock level, the following calculations are used:

ROP = (Demand x Lead time) + safety stock
Demand = Demand in weeks
Lead time = Lead time in weeks

Safety stock = csf x MAD x √ (Lead time)
Csf = customer service level
MAD = mean average deviation

Table 3.1: Example of the relation between service level and safety stock. (Slater, 2010, p.25)

No. of Spares Held	Probability of Event	Cumulative Probability
1	9.2%	9.2%
2	14.7%	23.8%
3	19.5%	43.3%
4	19.5%	62.9%
5	15.6%	78.5%
6	10.4%	88.9%
7	6.0%	94.9%
8	3.0%	97.9%
9	1.3%	99.2%
10	0.5%	99.7%
11	0.2%	99.9%
12	0.1%	100.0%
13	0.0%	100.0%
14	0.0%	100.0%

This formula is useful to show the difference in safety stock levels between a spare part in category A and a spare part in category B. For parts in category B, a service level of 90% might suffice, while the service level of parts in category A can be determined to be as high as 99%. This affects the safety stock level, as shown in table 3.1, where the cumulative probability functions as service level.

If the quantity at hand equals the reorder point, an order is placed. This order is equal to the economic reorder quantity (ROQ). To determine the economic reorder quantity, another formula is used (Chopra & Meindl, 2013):

$$\text{ROQ} = \sqrt{\frac{2 \times order\ cost \times Demand\ rate}{Item\ cost \times Holding\ cost}}$$

Order cost= cost for processing order and receiving the delivery
Demand rate = expected demand over a year.
Item cost= purchase cost of the item, including delivery costs.
Holding cost= percentage of the cost of a product, including cost of capital, handling cost an obsolescence cost.

Generating reliable data is crucial for spare parts management since the demand determines both the reorder point and reorder quantity.

Another option is to outsource the management of spare parts, this can be done with either a consignment inventory or a vendor managed inventory. Consignment inventory means that the supplier owns the inventory at the storeroom of the company. Payment occurs when the stock is issued for a work order. This strategy allows a manufacturer to produce by convenience and schedule, rather than by fluctuating demand. This benefits the facility as well, as it reduces inventory carrying costs, reaffirms Lean inventory management, and increases cycle time as downtime is minimized with this method (Smith & Hawkins, 2004).

With vendor managed inventory (VMI) on the other hand, the supplier is responsible for all decisions regarding product inventories at the retailer. The company shares the stock usage, allowing the vendor to better manage the supply chain to minimize the company's investment in inventory. According to *Lean maintenance* (Smith & Hawkins, 2004) the success rate is noteworthy. A successful implementation of this strategy takes detailed planning, solid management direction and commitment and an organization structure to allow the VMI to function as a member of the staff. According to a multiple-case study (Kauremaa, Smaros, & Holmstrom, 2009) implementing VMI can lead to both strategic and operational benefits for both the supplier and the buyer.

For both the consignment inventory and vendor managed inventory, the supplier is responsible for the risk. This would suggest this method is more expensive than managing the spare parts by the technical department. This is not the case however, since the supplier gains the benefit of being the sole supplier of the company with full visibility of the supply chain, allowing them to better time their supply chain activities to produce better results (Slather, 2010).

3.2.3. Notifications

Notifications, also referred to as maintenance workorders, are used to inform the maintenance department about the state of machinery. If a breakdown occurs, and the foreman of production calls an engineer to conduct a repair instead of writing a workorder, critical information is lost in the process. If a defect is observed that can cause severe damage to machinery or personnel, a call is necessary, but a work order should be made afterwards. The work orders are processed in the ERP system, this gives the opportunity to generate data for future reference. To do so, it is essential, and practical, to standardize the content of a notification. A well written notification provides the maintenance department the information needed to avoid a trip to identify the problem or to identify the materials needed (Mobley, 2004). The information can be used to locate bottlenecks in the production process. The ERP system at Company X provides options for the following information:

- Time and date of notification
- Time and date of breakdown
- Name of author
- Functional location (The code of the machinery in the ERP system, drop-down menu)
- Problem statement
- Location in plant
- Mitigating actions taken (repairs, changed settings or actions regarding safety)
- Required repair and test done by production team
- Disciplines needed (Mechanical Engineer, Electrical Engineer, Any engineer)
- Support needed (best assessment of what is needed, can be ladder or specific safety measures)
- Damage code
- Notification type (breakdown, non-breakdown, or information)
- Detailed problem description
- First assessment of priority

In section 2.2.3, the following example is given for the current use of notifications at company X.

Hi, there is some yoghurt on the floor, please come check it out.

Sender: Sven

By filling in the optional fields provided by the ERP system, this could be transformed to the following notification:

Created: 17/02/2021
Breakdown: 17/02/2021; 14:02
Sven Kamerling
Line 2; Yoghurt Packaging E3
Leakage Yoghurt pipeline
Line 2: Pipeline between fermenting and packaging
Taped off leakage, stopped production.
Stopped production, leakage stopped.
Discipline: Any engineer
Replacement of pipeline, tape is not acceptable by food regulations.
Damage code: 03 (fictional code for replacement)
Notification type: Breakdown
Problem description: Noticed yoghurt on the floor, noticed a hole in the pipeline between the fermenting and packaging machines.
Priority: 1

With this notification, the maintenance department has the information required to prepare the job. The job can be planned with a better time estimate, and the engineers have more knowledge on the required materials. After the job is finished, additional information is required to close the notification.

Parts repaired:
Cause description:
Damage description:
Description of corrective action taken:
Total costs and spend resources: (hours, materials, services)

This information can prevent the maintenance department from reinventing the wheel. Within the ERP-system, it is possible to find finished notifications to recall former actions. It helps to locate the machines that are causing the most expensive or most frequent breakdowns. Therefore, the notifications are primarily used for preventive maintenance, yet the data can be used for performance management.

3.3 Performance management in maintenance management

This section describes how performance management can be used in maintenance management. Without performance measurement, it is impossible to exert any control over an operation on an ongoing basis (Slack, Brandon-Jones, & Johnston, 2013). Each aspect of maintenance management provides the opportunity to measure a wide variety of *metrics*, varying from the total maintenance costs to the number of rejected notifications. An *indicator* is a combination of metrics, the number of rejected notifications divided by the total number of notifications for example. Monitoring and managing these indicators becomes more complex as the number of indicators increases. Therefore, it is important to select indicators that reflect the strategic objectives of a company, these are called the key performance indicators (KPIs).

Section 3.3.1 contains the general characteristics of key performance indicators. The balanced scorecard, a framework that is used to translate a strategy into objectives, is explained in section 3.3.2. In section 3.3.3, current uses of performance management in maintenance management are analyzed and combined to create a framework that is used in chapter 5 for the implementation of TPM at the maintenance department of company X. Section 3.3.4 covers the monitoring of key performance indicators.

3.3.1 Key performance indicators and performance measurement

As mentioned, key performance indicators are used strategically. The strategy and goals provide the reference point for other decisions, and the criteria against which to measure performance (Boddy, 2011). The goals, and thus the key performance indicators, follow the SMART criteria. SMART is the acronym for Specific, Measurable, Attainable, Realistic, and Time-bound. To use KPIs correctly for performance management, it is crucial to know what a KPI is measuring and why you are measuring it. Additionally, the performance of the responsible party must correlate to the value of the KPI. *Number of products produced* can be influenced by the maintenance team but is also influenced by production staff. Thus, to measure the performance of the maintenance team, choosing *uptime of machinery* as a KPI makes more sense. Most KPIs can be categorized in the five generic performance objectives, these objectives concern *Quality, Dependability, Speed, Flexibility, and Cost* (Slack, Brandon-Jones, & Johnston, 2013) . It is necessary to define the required data for the KPI, the measurement method, and the required tools for the measurement. Additionally, the frequency of evaluation needs to be predetermined (European committee for standardization, 2007).

After selecting the key performance indicators with these criteria in mind, the values can be compared to the targets of the company. These targets are set following the SMART criteria and are set before selecting KPIs. Setting targets, or goals, can be difficult if a company has no experience with performance management. Fortunately, other companies use a TPM based maintenance approach and thus use similar maintenance objectives. Benchmarking can be a useful to set realistic targets if the strategy of the other company aligns with the strategy of company X.

3.3.2 Balanced scorecard

When translating vision and strategy to key performance indicators, focusing on financial measures is a common pitfall. To complement financial measures with measures of the drivers of future performance, the balanced scorecard was introduced by Kaplan and Norton.

> “The balanced scorecard retains traditional financial measures. But financial measures tell the story of past events, an adequate story for which industrial age relationships were not critical for success. These financial measures are inadequate, however, for guiding and evaluating the journey that information age companies must make to create future value through investment in customers, suppliers, employees, processes, technology, and innovation.” (Kaplan & Norton, 1996)

The balanced scorecard divides strategy into four performance perspectives as presented in figure 3.4. These perspectives contain a balance between short- and long-term goals.

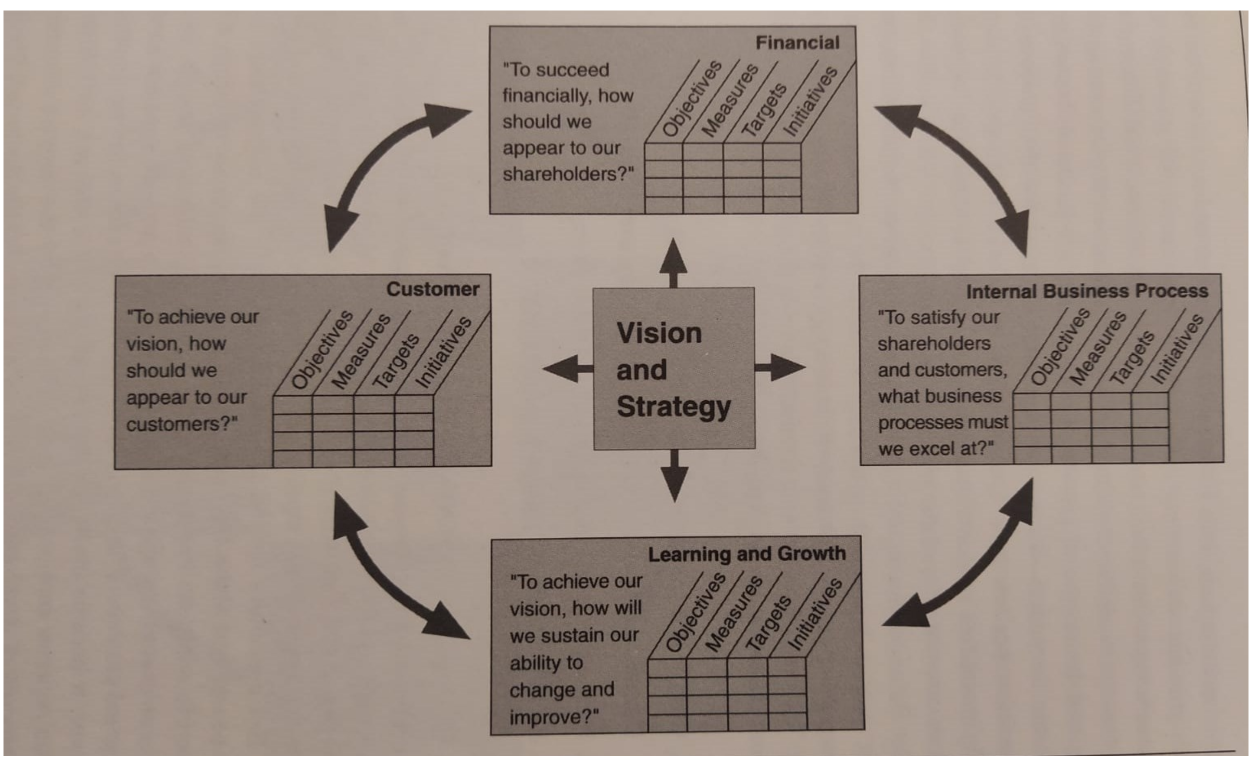


Figure 3.4: The four perspectives of strategy. (Kaplan and Norton, 1996, p. 9)

At first glance, this balanced scorecard can not directly be adapted for maintenance management since shareholders and customers are not directly linked to the maintenance department. The perspectives can be adapted to maintenance management by using the following descriptions (Biasotto, Dias, & Ogliari, 2010).

Financial perspective: Control and reduce the maintenance costs.
Customer perspective: The customer is the production team, thus improve availability and reliability.
Internal business process: Implement a planned maintenance system.
Learning and growth: Develop skills and prevent occupational accidents.

These four perspectives are considered when selecting the key performance indicators in maintenance management. For further reference, this approach is called the *Maintenance balanced scorecard*.

3.3.3 Performance management in maintenance management

There are other approaches to selecting key performance indicators, besides the *maintenance balanced scorecard*. The *indicator grid,* displayed below in figure 3.3.3, is used to divide KPIs in indicator groups and indicator levels. The groups can be compared to the maintenance perspectives and consist of economic, technical, and organizational indicator groups. Each group has indicators to measure performance of the company, the performance of production lines and the performance of a given equipment, these are the three indicator levels. Relevant indicators can only be determined by defining the objectives of each level. At the company level, the objective is to identify how maintenance can be managed to improve global performance. The objectives at the production lines are addressing performance factors, the improvement of availability and retaining health, safety, and environment preservation for example. At the equipment level, the objectives focus on better control of reliability, maintainability, and maintenance supportability. The strategy for which the KPIs are selected is formed by both external- and internal influencing factors. External influencing factors include culture, national labor cost, market situation and regulation, whereas the size of the plant, the age of the plant and the company culture are internal influencing factors (European committee for standardization, 2007). The indicator grid contains 71 indicators and are distributed as shown in table 3.2.

Table 3.2: The indicator grid, visualized in (Rødseth, Strandhagen, & Schjølberg, 2015)**, introduced in** (European committee for standardization, 2007)**.**

External Influencing factors

Internal Influencing factors

Indicator Groups \ Indicator Level	Level 1: Production plant	Level 2: Production line	Level 3: Equipment
Economic	6 KPIs	9 KPIs	10 KPIs
Technical	5 KPIs	2 KPIs	14 KPIs
Organisational	8 KPIs	2 KPIs	21 KPIs

A more practical approach is the approach referred to as the *maintenance manager approach* explained in Lean Maintenance (Smith & Hawkins, 2004). The maintenance objectives are being presented from the viewpoint of the manager of the technical department. The maintenance process is divided into areas, each with general indicators as presented in table 3.3. The KPIs presented in table 3.3 are utilized for a lean approach, instead of the TPM approach. As discussed in section 3.1.4, lean maintenance is too advanced to implement directly without having experience with total productive maintenance. While the maintenance objectives of TPM are similar to lean maintenance, it is possible that the indicators presented in table 3.3 are too advanced for the maintenance department at company X.

Table 3.3, Maintenance KPIs divided in maintenance responsibility areas (Smith & Hawkins, 2004, p. 40).

Reliability/Maintainability
- MTBF (mean time between failures) by total operation and by area and then by equipment.
- MTTR (mean time to repair) maintainability of individual equipment.
- MTBR (mean time between repairs) equals MTBF minus MTTR.
- OEE (overall equipment effectiveness) Availability × Efficiency (slow speed) × Quality (all as a percentage).

Preventive Maintenance (includes predictive maintenance)
- PPM labor hrs. divided by Emergency labor hrs.
- PPM WOs (work orders) #s divided by CM (corrective maintenance, planned/scheduled work) WOs as a result of PM inspections.

Planning and Scheduling
- Planned/Schedule Compliance—(all maintenance labor hours for all work must be covered and not by "blanket work orders"). This a percentage of all labor hours actually completed to schedule divided by the total maintenance labor hours.
- Planned work—a % of total labor hours planned divided by total labor hours scheduled.

Materials Management
- Stores Service Level (% of stock outs)—Times a person comes to check out a part and receives a stock part divided by the number of times a person comes to the storeroom to check out a stocked part and the part is not available.
- Inventory Accuracy as a percentage.

Skills Training (NOTE: A manager must notify maintenance craft personnel about the measurement of success of skills training.)
- MTBF.
- Parts Usage—this is based on a specific area of training such as bearings.

Maintenance Supervision
- Maintenance Control—a % of unplanned labor hours divided by total labor hours.
- Crew efficiency—a % of the actual hours completed on scheduled work divided by the estimated time.
- Work Order (WO) Discipline—the % of labor accounted for on WOs.

Work Process Productivity
- Maintenance costs divided by net asset value.
- Total cost per unit produced.
- Overtime hours as % of total labor hours.

NOTE: KPIs must answer questions that you as a manager ask in order to control your maintenance process. Listed is a sampling of recommended KPIs. They are listed by the areas in which a maintenance manager must ask questions.

There is an overlap between the *maintenance balanced scorecard*, the *indicator grid*, and the *maintenance manager approach*. Each method has specific advantages; thus, the challenge arises to use the methods complementary to create a framework for the management of the implementation of TPM at the maintenance department at company X.

The framework is based on the *maintenance balanced scorecard*. The maintenance balanced scorecard uses the multiple perspectives approach to combine short- and long-term goals. Since it is based on the balanced scorecard, a widely known and accepted management method, the maintenance balanced scorecard might be more recognizable for higher management. While justifying the maintenance budget, the maintenance balanced scorecard evades the pitfall of focusing solely on financial drivers.

The description of the internal business process in the *maintenance balanced scorecard*, implementing a planned maintenance system, is open to speculation. Using the *maintenance manager approach*, this description can be specified since the management areas in both TPM and lean maintenance are similar. Thus, the maintenance balanced scorecard, illustrated in figure 3.5, is updated to the *total productive maintenance balanced scorecard,* by selecting the management of total productive maintenance as the objective for the internal business process perspective.

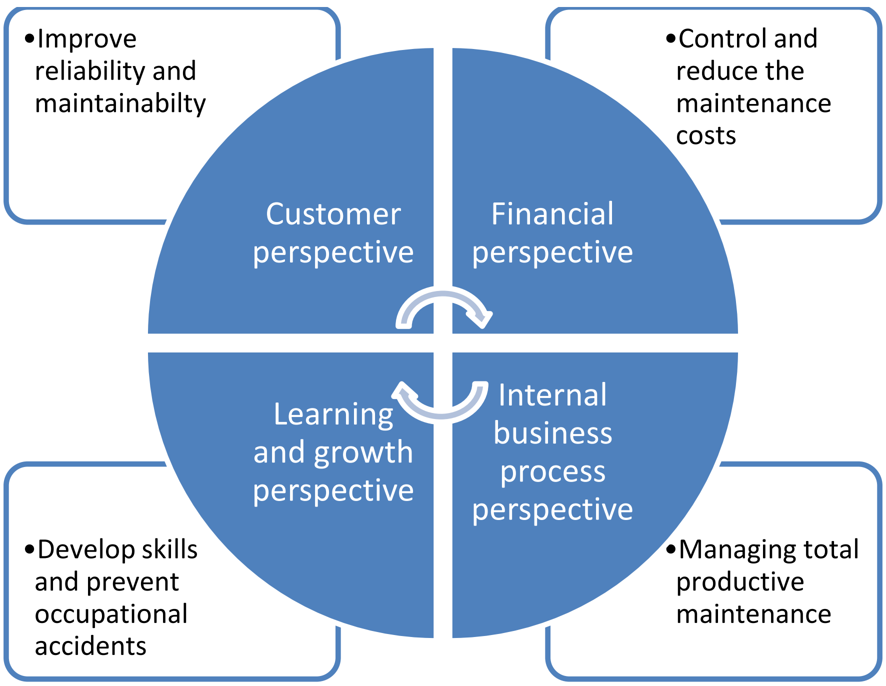


Figure 3.5: The total productive maintenance balanced scorecard

The work areas presented in table 3.3 can roughly be translated to the *total productive maintenance balanced scorecard* for potential key performance indicators:

- The work areas of preventive maintenance, planning and scheduling, materials management, and maintenance supervision are part of the managing total productive maintenance perspective
- The reliability/maintainability work area corresponds to the customer perspective
- The work process productivity area is part of the financial perspective
- The skill training is part of the learning and growth perspective.

The *indicator grid*, displayed in table 3.2, utilizes indicator levels to divide chosen KPIs between the different levels of maintenance. This division is helpful during the review of the maintenance objectives, a topic that is discussed in section 5.4. Combining the *indicator grid* with the *total productive maintenance balanced scorecard* results in the *TPM indicator grid* presented in table 3.4.

Table 3.4: The TPM indicator grid.

Objective \ Indicator level	Level 1: Production plant	Level 2: Production line	Level 3: Asset
Control and reduce maintenance costs			
Improve reliability and maintainability			
Develop skills and prevent occupational accidents			
Managing total productive maintenance			

This new grid is the framework for the implementation of TPM at the maintenance department of company X. While the *TPM indicator grid* provides broad objectives for the maintenance perspectives, yet the strategy of the maintenance department of company X determines how these objectives are reached. The resulting key performance indicators are positioned in the empty cells of the *TPM indicator grid*.

3.3.4 Monitoring key performance indicators

After the strategy of a company is translated into objectives, the objectives can be measured by using the key performance indicators. The targets can be set by using a benchmark or aiming for continuous improvement and are compared to the achieved values after a certain time. Ideally, the manager should immediately be warned if a KPI hints that there is something wrong. Thus, in the late 1990s, business-related digital dashboards began to appear (Kerzner, 2013):

Dashboards are visual display mechanisms used in an operationally oriented performance measurement system that measure performance against targets and thresholds using right-time data.

As the dashboard is being used as a visual display, it must be appealing and simple. It is unnecessary to display KPIs that can wait until the next evaluation. For example, displaying *Mean time between failures* is not recommended since it is not an actionable indicator at that moment. The KPIs that are selected to be on display can be tracked with the help of traffic light icons, trend icons, progress bars, or gauges, based on how the KPI is measured. Generally, the color indicates what action is needed. If the value is within the green area, work is progressing as planned. Yellow means caution, a potential problem that could harm the process. If the value is within the red area, instant action is required.

In conclusion, if the strategy of a company is translated into objectives using the different maintenance perspectives and maintenance levels, key performance indicators can be used to measure the progress of the strategy. By monitoring and evaluating the key performance indicators, with the dashboard as a visual monitoring system, the maintenance manager regains control over the maintenance processes, targeted investments can be made, and preventive actions can be taken.

3.4 Conclusion

Chapter 3 contains the literature study and provides answers to the corresponding research questions presented in section 1.3.3.

Which maintenance management approach has the most potential for company X?
Maintenance management has evolved from reactive maintenance into proactive maintenance. Within proactive maintenance, there are different approaches. After analyzing the current state of company X and the potential approaches, the conclusion is made that total productive maintenance suits the wishes of the company, while still being attainable. Total productive maintenance aims to increase the overall equipment effectiveness by establishing a comprehensive productive-maintenance system covering the entire life of the equipment, spanning all equipment-related fields, and, with the participation of all employees from top management down to shop-floor workers, to promote productive maintenance.

How can the maintenance policies be designed to support this approach?
Before total productive maintenance can be implemented, an update of the policies that are causing problems in the current situation is needed. The purchasing and warehousing of spare parts and the current use of work orders are responsible for high uncertainty and costs as described in section 1.2. The literature study provided a potential solution for the purchasing and warehousing of spare parts, by using consignment- or vendor managed inventory. The supplier is responsible for all decisions and risks regarding the inventory, while gaining the benefit of being the sole supplier for the maintenance department with full visibility of the supply chain. The work orders can be improved by using the already owned ERP notification template. The template provides the required information to prepare the jobs. After finishing the job, the template is filled out for future reference and potential investments.

How can performance management be used in maintenance management?
Performance management helps to monitor the progress by using key performance indicators. The strategy of the company is translated into key performance indicators using the *TPM indicator grid*, the product of combining different approaches in performance management with total productive maintenance to ensure balance between perspectives. The resulting *TPM indicator grid* is presented in table 3.4. Using a dashboard to support monitoring and evaluating the key performance indicators in real time, the maintenance manager regains control over the maintenance processes and targeted investments can be made and preventive actions can be taken.

4. Implementing a preventive maintenance plan for company X

Prior to implementing performance management into the maintenance plan of company X, the foundation of TPM must be implemented. The purpose of this chapter is to implement total productive maintenance into the maintenance plan of company X. For a successful integration of TPM into the maintenance plan of company X, the current maintenance plan must be updated to a comprehensive productive-maintenance system. That system, as stated in section 3.1.2, covers the entire life of the equipment, spans all equipment-related fields, and, with the participation of all employees from top management down to shop-floor workers, promotes productive maintenance. To achieve this productive maintenance system, both the structure of the maintenance department and the protocols in the maintenance department are subject to change. This translates to the research questions that are answered in this chapter:

- *How does the transition to preventive maintenance affect the structure of the maintenance department?*
- *How can the maintenance policies found in the literature study be implemented in the maintenance plan?*

Section 4.1 describes what elements characterize the structure of a TPM organization, and how this affects the structure of the maintenance department of company X. Section 4.2 has the purpose of illustrating a TPM plan for company X, including the policies described in section 3.2 and the TPM structure described in section 4.1, by following the process of a work order. Suggestions regarding the implementation of the total productive maintenance plan are discussed in section 4.3. A summary is provided in section 4.4.

4.1 Organization structure

The participation of all employees in promoting productive maintenance is the essence of TPM. Expanding the maintenance responsibilities across departments increases the risk of miscommunication, so a clear division between roles and responsibilities is necessary. This division of roles and responsibilities between divisions and within the maintenance department when using TPM is the topic of section 4.1.1. Section 4.1.2 discusses how this affects the organization structure of company X.

4.1.1 A total productive maintenance organization

This section covers the division of roles and responsibilities between departments and within the maintenance department. For many departments, the responsibilities are confined to supporting the maintenance department when necessary. The production department, however, has a special role since they co-operate with the maintenance department. While the maintenance department has a clear supportive role, since they are responsible for the upkeep of machinery, the production department can support the maintenance department by being responsible for the following actions:

- Cleaning equipment after use

- Being the eyes of the maintenance team
- Being trained to perform routine maintenance tasks
- Being trained to write standardized work orders

The maintenance department itself has three distinct functions in a TPM organization (Smith & Hawkins, 2004)

- Work execution
- Planning and scheduling
- Maintenance engineering

The work execution team is responsible for all preventive and emergency maintenance tasks. This can be divided in a preventive maintenance team, without the distractions of breakdowns, and an emergency maintenance team. This can only be done if the work execution team consists of multiple engineers.

The planning and scheduling team is responsible for preparing each job. For a job to be classified as correctly planned, the required manpower, materials, and equipment must be present at the jobsite, which must be adequately prepared and idle. The planning team schedules by priority, but all jobs must be accomplished.

The maintenance engineering team focusses on overarching problems or opportunities for the maintenance department. Installing new machinery, setting up lubrication routes to prevent rust or erosion, identify costly equipment problems, and monitoring the use of TPM are responsibilities of the maintenance engineering team.

4.1.2 Division of roles at company X

This section discusses the challenge of implementing the roles described in section 4.1.1 into company X. While the division of responsibilities between departments is clear, the implementation can prove difficult since the production department gains responsibilities and must train personnel for these responsibilities. Therefore, the overall goal, improving the overall equipment effectiveness (further described in section 5.2.4), of TPM must be clear to the production department. Since production shifts at company X often contain temporary workers and funds are limited, the company can opt for the training of foremen at first, since there is always one present at each production line.

Since company X has a complex organizational structure, consisting of few engineers that are spread across three locations, the division between roles within the maintenance department is a challenge. The distribution of engineers between locations is based on the difference in workload, as shown in figure 4.1. While management desires more co-operation between locations, it may be harmful to make an engineer of location A responsible for a role in location C, since it troubles the crucial relation between the production- and maintenance departments at location C. Transferring an engineer from location A to location C causes problems at location A, while hiring an additional engineer for location C is a disproportionate measure.

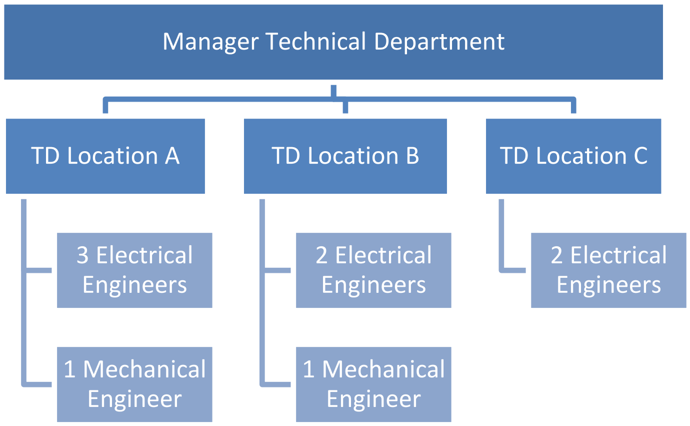


Figure 4.1: Organization chart of maintenance department

The additional workload for the maintenance department created by using the TPM roles is compensated by the production department that executes basic maintenance work. In return, the production team can expect higher availability of machinery. As mentioned in the literature study, vendor-managed inventory can be utilized as a solution for the workload associated with managing the inventory, so the maintenance department can focus on implementing TPM and its roles.

The planning and scheduling role is crucial for total productive maintenance, thus having an engineer with this role at each location is recommended. After confirming that a job notification is complete, the engineer sets a priority for the job, consulting the manager of the technical department if necessary. For each job, the engineer estimates the time, manpower, equipment, and materials that are necessary for the job by consulting the history of similar jobs in the ERP system. With this information, the engineer can team up with the planning division of the operations department to schedule the jobs. Lastly, the planning engineer can put together a maintenance kit with the required items and information for the upcoming jobs, so the work execution engineer has minimal downtime between jobs. The engineer at location C must collaborate with the planning engineer from another location if the job requires a mechanical engineer.

Based on the workload and available engineers at each location, the work execution team can consist of multiple engineers at company X. If a location has a single engineer for this role, he is responsible for both preventive and emergency maintenance. This is not an optimal solution since each emergency maintenance task will disrupt the planning. Locations with multiple engineers in this role can distinguish preventive from emergency responsibilities. The engineer that is responsible for emergency maintenance can be given jobs that can be interrupted without risk.

The maintenance engineering team is the only team that can work across all locations, since the information required for this role is available through the ERP system. Other responsibilities associated with this role can be done by the engineers with other roles if they completed their tasks. This is similar to the current situation as described in section 2.1, in which engineers work on projects or modifications if there is no job at hand. Comprehensive tasks like the installation of machinery can be planned by the planning and scheduling team. Since the tasks for this team are often unique, expensive or have a strategic element, it is recommended to involve the manager of the maintenance department.

To conclude, by collaboration between departments and utilizing vendor-managed inventory, it is possible to implement TPM in the maintenance department at company X. The redistribution of engineers between locations is not necessary, since the number of engineers is linked to the workload at each location. By assigning roles to the engineers, productivity and workflow can be improved. The manager can assign roles based on preferences of engineers, for example, engineers that are very structural can thrive in the execution team, while a more creative engineer might opt for the planning or maintenance engineering team.

4.2 Redesigning the work order process for company X

The roles and responsibilities are now divided between departments and within the maintenance department. Since company X aims to adapt preventive maintenance management, the current reactive method used for maintenance jobs becomes insufficient. Therefore, a method that embraces the concept of TPM can be implemented. This section has the purpose of illustrating how the productive maintenance system, with the division of roles and implemented policies as described in section 3.2, is used in practice by following a job throughout the *work order protocol* illustrated in figure 4.2.

Figure 4.2: The work order protocol

The steps of the *work order protocol* are described in the sections 4.2.1 up to and including 4.2.6. The *work order protocol* is based on the steps of the protocol for requesting a modification, as described in section 2.2.4.

4.2.1 Writing a notification

A job is created when an employee or the ERP system produces a notification. As mentioned in section 3.2.3, standardized notifications ensure the planner has the information required to determine job priority and give insight in the equipment history. With the help of the computerized maintenance management system of the ERP system, preventive maintenance tasks can be generated periodically based on suggestions in the manuals. The foremen of the production team can be trained to search for anomalies at the production line and write proper notifications.

4.2.2 Gatekeeping

Before the job request is planned, the planner must decide if the job should be planned. If the job notification is not filled out correctly, the notification is rejected and returned to the applicant. The job request is also rejected if the job does not add value or if the job is a modification. If the job notification is complete, the planner must decide if the maintenance department is responsible for the completion of the job. If the maintenance team is responsible, the job receives a priority level. To help determine the priority level, a prioritization matrix can be put in place that takes the possibility of an event and the impact of an event into account. Safety, environmental, quality, loss of production, and financial concerns are factors that determine the impact. The priority level determines the time interval in which the job must be completed (within a day, week, or month for example).

4.2.3 Planning the job

If the work order is approved and the time interval is determined, the job can be planned. As mentioned, planning jobs has an important role within total productive maintenance. Planning a job consist of three steps: developing a plan, securing parts and services, and preparing the kit.

The planner develops a plan by describing the main tasks, the duration of each task, and required resources like materials, equipment, manpower, permits, and contract services. To plan each job, the planner has access to previous plans, bills of materials, and manuals. After the resources are determined, the cost of the job can be estimated. If the cost transcends a certain threshold, that is dictated by the maintenance manager, the plan must be approved by the maintenance manager before the resources can be ordered.

If the plan is approved, the parts and services can be secured. The priority level determines the time interval of the job, but the job has not been scheduled yet. Most materials, equipment, and permits can be ordered before a job is scheduled, if the holding costs are negligible in the time interval. Some necessities can only be secured after a job is scheduled, for example, hiring a contractor for a certain week instead of a certain part of a specific day is unwise. However, the planner can call contractors to check availability.

If the parts are secured, the maintenance kit can be put together. The maintenance kit contains all necessary materials and tools to execute the job. If done correctly, the maintenance kit eliminates search- and transport- time for the engineer of the execution team. Preparing the maintenance kit at least a day prior to the job can serve as a final check to make sure all materials are secured.

4.2.4 Scheduling the job

After the job is correctly planned, the job can be scheduled. For the jobs that take place at the production line, the maintenance planner must cooperate with the production planner. When an engineer arrives for a job, the production line must be prepared and idle for the engineer to work safe and efficient. As mentioned in section 4.1, the roles of the engineers can influence the schedule. Jobs that cannot be interrupted without risk should not be scheduled for the engineer that is responsible for the emergency maintenance jobs if avoidable. Efficient schedules can eliminate waste, by combining jobs for a production line to reduce the preparation time for example.

4.2.5 Executing the job

Gatekeeping, planning, and scheduling jobs by using the descriptions above can be seen as an investment required for total productive maintenance. The execution phase of the job illustrates an improvement that is a result of this investment.

The engineer of the work execution team walks into the workshop and picks the maintenance kit that is prepared for the job on his schedule. The engineer checks the job plan to make sure he understands what he is supposed to do and subsequently checks if the maintenance kit is complete, and the permits are correct. He arrives at a clean, safe, and prepared production line, and he executes the job following the plan. If the plan proves to be insufficient for the job, the engineer notifies the planner and the production foreman to discuss if the job must be rescheduled or can be continued. After the job is done, the engineer analyses the cause of the problem if the job was not a periodic measure. Now, the production team checks if the problem is indeed solved. Lastly, the notification is updated to resemble the notification described in section 3.2.3, by adding the location of the problem, and description of the cause and the resources spent for example. The work order can now be closed, and the engineer moves on to the next job on his schedule.

4.2.6 Reviewing the job

While the work order is closed, there is another step in the work order protocol. After each completed job, the planning engineer evaluates the maintenance plan by comparing the estimated time, equipment, spare parts, and work method with the actual values. If there is a discrepancy between the plan and actual performance while there is no indication it was caused by a one-off event, the job plan must be improved. While working with this system, the job plans will continuously improve in accuracy.

4.3 Implementation plan for company X

This section contains suggestions for the maintenance department about the implementation of the preventive maintenance plan. Fortunately for company X, other companies have experience with the implementation of a total productive maintenance plan. The lessons that are provided in these case studies are discussed in section 4.3.1, in addition to a general implementation framework. In section 4.3.2, an implementation plan is presented for the maintenance department of company X.

4.3.1 Implementation of TPM

The transition from corrective maintenance to preventive maintenance is a process that requires support throughout the company. Implementing the suggestions described in sections 4.1 and 4.2 affect the structure of the maintenance department, the division of roles and responsibilities between different departments, and the way engineers think about maintenance. A case study on the implementation of TPM in large and medium size organizations suggest the implementation relies on commitment from management and the workforce, a total focus on quality and a willingness to change and to be flexible (Aspinwall & Elgharib, 2013). There is typically initial resistance that management must overcome, and management must also encourage TPM's development during its infancy (Park & Han, 2001). To overcome resistance, Park and Han divide the implementation in four stages:

Stage 1: Preparation

Management is responsible for creating an TPM-friendly environment. A committee can be formed to promote and coordinate the implementation of TPM. A TPM-based maintenance plan is created, along with a plan for the training of personnel.

Stage 2: Preliminary implementation

Personnel receives training for their new responsibilities. Maintenance engineers support the operators in their efforts to execute basic maintenance tasks.

Stage 3: TPM implementation

The maintenance plan is implemented in this stage. The maintenance plan targets low hanging fruits to gain momentum and overcome resistance. This stage is crucial for the success of TPM and must overcome the increasing workload of the engineers, who are supporting the operators and creating maintenance plans on top of their regular responsibilities.

Stage 4: Stabilization

After the dust of the implementation has settled and the operators can autonomously execute basic maintenance tasks, the maintenance department keeps pushing for continuous improvement. Major losses are located with the overall equipment effectiveness, explained in section 5.3.6, and eliminated.

In practice, the boundaries between stages can fade. The implementation of TPM in a Chinese manufacturing company began with a one-year pilot phase. Afterwards, a two-year promotion and consolidation phase began, followed by a two-year maturity phase. In these phases, 12 implementation steps are taken, displayed in figure 4.3. Giving operators a sense of ownership over the machines to internalize caring about the condition of the machines is suggested (Tsang & Chan, 2000).

Phase	Steps	Status in the case study
Pilot phase	T1 Announcement	The introduction of TPM was announced through internal correspondence and posters on TPM notice-boards. The maintenance manager was appointed the champion of TPM
	T5 TPM master plan	The master plan was developed by the TPM champion
	T3 Organize and promote TPM	A TPM committee was formed to steer the implementation programme and monitor progress
	T2 Education campaign	Training on TPM concepts for supervisory staff was conducted by the champion. This was followed by training courses for operators focusing on discipline, proper use of equipment, cleaning and lubricating
	T6 TPM kick-off	No special event was organized to kick off the programme
	T7 Improve equipment effectiveness	This was initially focused on two pilot sites. The improvements were made by the maintenance department
	T8 Develop an autonomous maintenance programme:	
	A1 Perform initial cleaning A2 Address sources of contamination and inaccessible places A3 Establish cleaning and lubricating standards	Tasks A1-A3 were performed by the maintenance department in collaboration with production. Visual controls such as equipment nameplates and correct operating range displays on gauges, valve on-off indicators, etc. were introduced. Photographs were used to document the desired cleanliness of equipment and the workplace
	A4 Set overall inspection standards	Inspection checklists were prepared by maintenance
Promotion and consolidation phase	T4 Establish basic TPM policies	The operator is responsible for providing primary care for his equipment – cleaning, lubricating, adjusting and inspecting
	T2 Education campaign T8 Develop an autonomous maintenance programme – steps A1-A4	Steps T2 and T8 were extended to all production units
Maturity phase	T9 Develop scheduled maintenance programme	This is being done by maintenance
	T10 Conduct training to improve operation and maintenance skills	There is ongoing effort to prepare operators for the challenge of autonomous maintenance
	T11 Develop an early management programme	Data are being captured to track equipment performance and optimize maintenance decisions
	T8 Develop an autonomous maintenance programme:	
	A5 Set autonomous maintenance standards	Simple PM tasks have been included in autonomous maintenance
	A6 Assure process quality A7 Autonomous supervision	There is ongoing training to enhance operators' awareness of the causal relationships between equipment conditions and output quality, and develop their data analysis and problem-solving skills for maintenance improvement
	T12 Perfect TPM implementation	This is the ultimate target to be accomplished

Figure 2.3: Steps for implementing TPM (Tsang & Chan, 2000, p. 153)

During the implementation of TPM in the Land-Rover manufactory, the 12 steps are extended to add more detail. The implementation covers a general implementation of TPM methods, after which the maintenance department targets a machine individually. From the announcement that TPM will be implemented to the handover of the first machine to the operators took 21 weeks. Subsequent machines took 10-13 weeks each, since TPM was already established (Bohoris, Vamvalis, Trace, & Ignatiadou, 1995).

4.3.2 Implementation of TPM at company X

The implementation stages and steps for the implementation can be tailored to an implementation plan for company X.

1. The announcement of TPM: the maintenance manager of company X announces to different stakeholders that TPM is to be implemented, and how TPM benefits and affects each stakeholder.
2. Outsourcing spare part management: prior to proceeding with the implementation process, a vendor can be found to outsource the purchasing and warehousing challenges for the maintenance department, so the focus is on the implementation of TPM.
3. Development of a training plan: a plan is created to train the stakeholders on their TPM responsibilities.
4. Stakeholders receive training: the engineers receive their training on the basics of TPM, the *work order protocol*, and the TPM roles. The operators receive training on basic maintenance tasks.
5. Preparing the ERP system: the ERP system must be arranged to meet the required standards for the *work order protocol*.
6. Preparing the dashboard: the maintenance manager decides how the KPIs are presented on his dashboard.
7. Implementing the *work order protocol* and using the TPM roles: after having received training, the operators start to perform basic maintenance tasks supported by the maintenance department. The engineers work according to their TPM roles, using the *work order protocol*. The maintenance engineering team supports the operators and helps the executive maintenance team during this stage of the implementation.
8. Handing over the responsibility of basic maintenance to the operators: after being supported for some time, the operators execute basic maintenance tasks autonomously.
9. Planning preventive maintenance tasks: as the workload decreases due to the autonomous basic maintenance, the planning engineers can start planning preventive maintenance.

10. Re-establishment of the maintenance engineering team: the engineering maintenance team foregoes most of the supportive work and can focus on the responsibilities as described in section 4.1.1.
11. Using OEE to locate waste: having gathered more data from working with the *work order protocol*, the maintenance manager utilizes the overall equipment effectiveness to identify areas with the highest losses.
12. Continuous improvement: after successfully completing all the previous steps, new challenges will surface that affect the maintenance objectives for company X. New KPIs can be selected for these maintenance objectives.

Using these 12 steps, the Gantt chart that is presented in figure 4.4 can be created. Time estimations are based on the Land-Rover case study, the current situation at company X, and the size of company X.

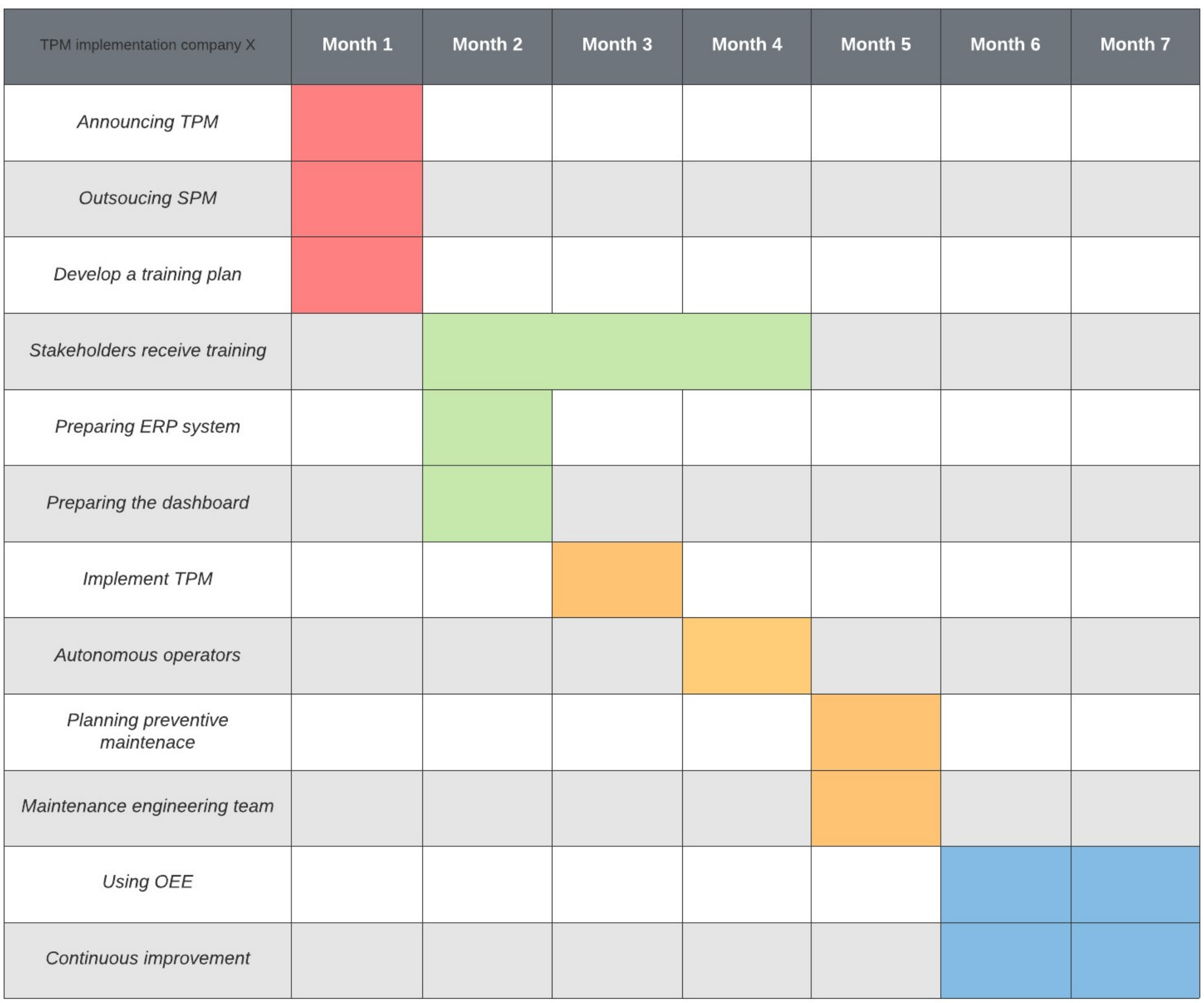


Figure 4.4: The estimated implementation schedule for company X

The Gantt chart, displayed in figure 4.4, is divided by color in the four implementation stages. During the preparation stage TPM is announced, spare part management is outsourced, and a training plan is created. The preliminary implementation stage is used to start the training of stakeholders, preparing the ERP system, and preparing the maintenance dashboard. As soon as the total productive maintenance plan is introduced, the implementation stage begins. Throughout this stage, operators gain ownership over the machines, preventive maintenance tasks are planned, and the maintenance engineering team shift their priorities from supporting other teams to fulfilling their own responsibilities. The stabilization phase, where OEE is used to reduce waste and the maintenance department aims for continuous improvement, completes the implementation of TPM.

4.4 Conclusion

Chapter 4 suggests how principles of TPM can be implemented at the maintenance department of company X and provides answers to the corresponding research questions presented in section 1.3.3.

How does the transition to preventive maintenance affect the structure of the maintenance department?

TPM relies on a clear division of roles and responsibilities, both between departments and within the maintenance department. Apart from the production department, all departments can support TPM by supporting the maintenance department when necessary. In TPM, the production department and maintenance department cooperate. The production department is responsible for:

- Cleaning equipment after use
- Being the eyes of the maintenance team
- Being trained to perform routine maintenance tasks
- Being trained to write standardized work orders

In return, the maintenance department utilizes TPM to improve reliability and uptime of machinery.

Within the maintenance department, teams are created for the following responsibilities:

- Work execution
- Planning and scheduling
- Maintenance engineering

For company X, this division is complex due to a limited number of engineers and multiple locations. Since the number of engineers is linked to the workload at each location, a redistribution is not necessary. By assigning the roles to the engineers, both productivity and workflow can be improved.

How can the maintenance policies found in the literature study be implemented in the maintenance plan?

After adapting to an organizational structure that supports TPM, including cooperation between departments and utilizing maintenance roles, a TPM centered maintenance plan can be implemented. Vendor-managed inventory replaces the current purchasing and warehousing procedures, so the maintenance department can focus on the transition from a reactive to a preventive maintenance approach. Standardized notifications are implemented and used in the *work order protocol*. This protocol aims to eliminate waste at each step in the work order process. The *work order protocol* supports preventive maintenance by utilizing continuously improved job plans and by generating data for further reference.

To overcome resistance, an implementation plan must be created. Learning from the lessons of other companies that implemented a total productive maintenance plan, an implementation plan for company X was set up. The implementation plan covers four stages and consist of 12 implementation steps that are planned in the Gantt chart (figure 4.4).

5. Introducing performance management at company X

After implementing the productive maintenance system and the work order protocol as described in Chapter 4, this chapter introduces performance management at company X following the method described in section 3.3. This corresponds to the following research question:

- *How can performance management be used to monitor the transition to preventive maintenance at the maintenance department of company X?*

Section 5.1 covers the new maintenance strategy of company X, that is defined by both internal and external influences. The objectives corresponding with the strategy are described in section 5.2. Section 5.3 covers the selection of key performance indicators that are derived from the objectives. Suggestions regarding the monitoring of key performance indicators are covered in section 5.4. Section 5.5 functions as the conclusion for this chapter.

5.1 Forming the strategy of the maintenance department at company X

As mentioned, the first step in performance management is to define the strategy for a company or, in this case, a department. The strategy is subjected to both internal and external influences. Therefore, section 5.1.1 covers the internal influence, while the external influences are discussed in section 5.1.2. Section 5.1.3 combines the influences into an overarching strategy.

5.1.1 Internal influences

Internal influences cover all influences that can be controlled by company X. Some influences originate from the maintenance department, others arise from higher management or other departments. The strategy that is sought after by the maintenance manager is having control over the performance of the maintenance department. The maintenance budget, the reliability of machinery, safety issues, the job satisfaction of engineers, and spare parts management are areas of interest when discussing the performance of the maintenance department.

Logically, the production department will encourage the improvement of the reliability aspect of the performance of the maintenance department. Meanwhile, the R&D department relies on the support from engineers for modifications to facilitate the production of new products.

Additionally, company X promotes its brand as a local dairy producer that works with local farmers and happy cows that graze in a meadow. In short, a company that embraces a green image. Praiseworthy, but not in line with the current situation within the factory, where each ordered part is delivered separately, and gallons of dairy products are wasted each time a breakdown occurs. Therefore, management urges to improve on these aspects.

5.1.2 External influences

Apart from the internal influences that affect the strategy of the maintenance department, some external factors must be considered. External influences form conditions that are outside the control of company X. For the maintenance department, the main influencing factors are regulations and changes within the sector.
Since company X produces dairy products for consumption, company X must follow the regulations that apply to the food industry. According to the maintenance manager, the food industry regulations affect the maintenance department in two ways. Firstly, dairy products are easily contaminated, therefore food regulations dictate that both the engineer and the equipment must be disinfected before entering the production hall. To top it off, for the dairy products made from goat milk, the engineer and the equipment must be completely sterile. Secondly, the food industry regulations affect the maintenance department regarding the quality of products. Each product must meet high standards to be sold since the product is edible. If a breakdown occurs that affects the production process, the batch is potentially wasted. This external influence fuels the internal influences discussed in section 5.1.1.

Another factor that influences the strategy of the maintenance department is the supply chain. For company X, the introduction of order costs by the suppliers meant that the current purchasing policy became obsolete. Additionally, for the older machinery at company X, spare parts or service contracts may become unavailable. This can create a dilemma between an investment in new machinery or in training and spare parts for the current machinery.

5.1.3 The strategy of the maintenance department at company X

To implement performance management, the maintenance department at company X must decide what strategy to follow. The maintenance manager requires a strategy that results in an increase of control over the maintenance department. Derived from the literature study (section 3.1.4), this strategy that suits the maintenance department will be in line with total productive maintenance.

With the identification of the internal and external influences on the strategy of the maintenance department of company X, the suitability of TPM for company X can be checked. If the implementation of TPM leads to a conflict with the influencing parties to an unmanageable extent, TPM may not be a feasible strategy. Therefore, the concern and possible consequence of implementing TPM for each influencing party is reviewed below. Since the consequences depend on many factors, the predicted outcomes presented here can differ substantially from the real consequences. Taking this into account, the assumption is made that the proposed measures are implemented and executed as intended.

The internal influencing parties referred to in section 5.1.1 are:
(i) The *maintenance manager* concerned with the performance of the maintenance department, consisting of the maintenance budget, the reliability of machinery, safety issues, the job satisfaction of engineers, and spare parts management. As described throughout this report, TPM is a method that is developed to gain control in all these areas.

(ii) The *production department* that encourages the improvement of reliability of the machinery. TPM is used in preventive maintenance to prevent breakdowns, so an improvement in reliability is likely. The consequences of TPM in the renewed cooperation between the production and maintenance departments, and the conclusion that it is beneficial for both departments, are discussed in section 4.1.2.
(iii) The *R&D department* relying on the support of engineers for modifications. With the maintenance roles introduced in section 4.1, the aid of the maintenance engineering team can be requested. This is an improvement over the current situation, where modifications only take place in the downtime of engineers.
(iv) *Higher management* embracing the green company image, where the latter is being threatened by the numbers of delivery vans and the waste caused by the many breakdowns. Using vendor managed inventory and improving reliability with TPM is more in line with a green company. Purely coincidentally, an efficient order method combined with a reduction in waste of product benefits the company financially as well.

The external influencing factors discussed in section 5.1.2 are:
(i) The *regulations regarding hygiene* in the food sector that underline the importance of the *work order protocol* described in section 4.2. Since each trip to the production line means either disinfecting or sterilizing the equipment, reducing the number of trips is lucrative.
(ii) The *regulations regarding food safety* that result in waste of product when an anomaly occurs. The waste of product can be reduced by improving reliability, since a reduction in breakdowns means a reduction of discarded product. As mentioned, TPM improves reliability.
(iii) The *developments in the field of maintenance* that induce investment opportunities. The use of TPM, the notifications and the maintenance engineering team can improve judgement over decisions regarding these investments.
(iv) The *uncertainties in the supply chain* associated with the management of spare parts. The use of vendor managed inventory can create a steady and clear structure that reduces the vulnerability to influences originating in the supply chain. On the other hand, having a sole supplier increases the influence the supplier has on the strategy. Agreeing upon lead times and spare part availability in a contract, for example, can reduce this influencing factor.

To conclude, the strategy of using total productive maintenance, the *work order protocol*, and the use of vendor managed inventory as described in chapters 3 and 4 does not conflict with either internal or external influences. Moreover, the internal influencing parties, all part of company X, potentially benefit from this strategy.

5.2 Maintenance objectives for company X

After verifying the strategy, the objectives for the implementation of the strategy can be set. Since the strategy is based on total productive maintenance, it makes sense to use the total productive maintenance objectives described in section 3.3.3. The four main objectives derived from the maintenance balanced scorecard presented in that section correspond with sections 5.2.1 through 5.2.4. Section 5.2.1 focusses on the control of maintenance costs. The improvement of reliability is the topic of section 5.2.2. The development of skills and the prevention of accidents is discussed in section 5.2.3. Section 5.2.4 covers the management of total productive maintenance, including the *work order protocol*. In section 5.2.5, the objectives for the implementation of TPM are implemented in the maintenance indicator grid that is presented in section 3.3.3.

5.2.1 Control of the maintenance costs

The objective corresponding with the financial perspective is the control of maintenance costs. To control the maintenance costs, it is necessary to understand the expenses. According to the maintenance manager, the maintenance department of company X exceeded the maintenance budget in recent years. While the manager can put his finger on the weak spots, namely the high (emergency) order costs combined with the high costs associated with reactive maintenance, the exact costs of the expenses are unknown. The costs are not defined properly in the current situation since the administration has a low priority for the maintenance manager, who is busy putting out the fires that are lit up by the many breakdowns.

Thus, to control the maintenance costs, the maintenance department must gain insight into the maintenance expenses. This is the objective during the implementation process of the new strategy, on which the key performance indicators from the financial perspective are based.

5.2.2 Improve the reliability of machinery

As mentioned in section 3.3.3, the production department can be seen as the customer of the maintenance department. For this perspective, the objective is to improve reliability and availability of the machines at company X. While both are likely to improve by using preventive maintenance, there is a challenging period during the transformation between reactive and preventive maintenance. During this period, engineers are still busy with the breakdowns caused by the reactive maintenance, while they conduct preventive maintenance tasks. Furthermore, it is not realistic to expect the production team to execute their basic preventive maintenance tasks smoothly during the implementation phase. If possible, this transition can be facilitated by assigning - during this phase - some of the preventive maintenance tasks to the engineers of the maintenance engineering team.

To achieve the improvement of reliability and availability, focusing the objectives on the transformation from corrective to preventive maintenance during the implementation process is advisable.

5.2.3 Developing skills and preventing accidents

For the learning and growth perspective on total productive maintenance, the objective is to develop skill and prevent accidents. The development of skills is not restricted to the maintenance department since the production team is involved as well. As mentioned in the total productive maintenance roles, the production team at company X is responsible for executing the routine maintenance tasks and submitting correctly written notifications on encountered abnormalities. To do so, a basic knowledge of maintenance and the machines is necessary. For the engineers, the transformation from corrective to preventive maintenance requires a different approach towards their job. This can be developed by gaining experience with TPM, the *work order protocol*, and the maintenance roles. Correctly using the work order *protocol* contributes to the prevention of accidents, by preparing the jobsite, making sure the machines have been shut off prior to the arrival of the engineer, and by the usage of the job plan.

Therefore, the objectives for the maintenance department during the implementation of total productive maintenance at the maintenance department of company X derived from the learning and growth perspective are:

- Teaching the production team on how to fulfill their maintenance responsibilities
- Developing affinity with the work methods associated with TPM
- Prevent accidents by using the work order protocol

5.2.4 The management of total productive maintenance

The objectives mentioned in the sections above facilitate a successful implementation of TPM at company X. During the implementation phase, the objective associated with the internal business process perspective is to monitor the implementation of TPM, the *work order protocol*, and vendor managed inventory.

After the implementation of TPM, the maintenance objectives are replaced. The continuity of TPM becomes the main objective for the internal business process perspective. In section 6.2, recommendations are included that discuss the objectives for the different perspectives that can be used if the maintenance department has successfully implemented TPM.

5.2.5 Updating the maintenance indicator grid for the implementation process

As discussed in sections 5.2.1 through 5.2.4, the objectives from the perspectives in the maintenance indicator grid are different during the implementation process, thus a separate grid is required for the implementation phase. For further reference, this new grid is called the TPM implementation grid, and is shown in table 5.1. The TPM implementation grid functions as an overview of the key performance indicators, for each objective on each level.

Table 5.1: The TPM implementation grid. In the entries of the table, key performance indicators are to be positioned

Objective \ Indicator level	Level 1: Production plant	Level 2: Production line	Level 3: Asset
Gain insight in the maintenance expenses			
Make the transition to preventive maintenance			
Teach the production team to fulfill their maintenance responsibilities			
Develop affinity with the work methods associated with TPM			
Prevent accidents by using the work order protocol			
Monitor the implementation of TPM			

Since there are three objectives originating from the learning and growth perspective, the number of objectives is adjusted. Since each objective is measured by its own key performance indicators, each objective receives a separate row in this table. An attempt is made to maintain the visual balance between perspectives by grouping these objectives together with the use of shades.

5.3 Key performance indicators for the maintenance department at company X

Performance management is the cornerstone for success in both the implementation and the continuation of TPM. By using the TPM implementation grid, key performance indicators are selected to measure the performance on each objective. The KPIs are selected in sections 5.3.1 through 5.3.6, each section corresponding with one of the objectives of the implementation grid. For each objective, a brief explanation on how the methods proposed in this report contribute to this goal is provided. Lastly, in section 5.3.7, the TPM implementation grid is filled in with the selected key performance indicators.

5.3.1 Gain insight in the maintenance expenses

Insight in the expenses of the maintenance department is not only required by the financial department, but it also provides an opportunity for the maintenance manager to eliminate waste. The understanding of what the costliest factors are for the department supports the opportunity to take targeted measures to reduce costs. This understanding is supported by using notifications in the ERP-system, as explained in section 3.2.3. Within each notification, both for maintenance jobs and modifications, the ERP-system provides input cells for cost factors such as material- or labor costs. Inevitably, costs are made by the maintenance department that should not be attached to a job to ensure the correctness of the cost of a job. However, incidental costs like spare parts that are damaged beyond repair during transport for example, must be accounted for. The costs that are made by the maintenance department but are not assigned properly are labeled miscellaneous costs. To gain insight in the expenses, the costs that are labeled miscellaneous costs must be reduced. To monitor the use of the notifications and the reduction of miscellaneous costs, the following key performance indicators are selected:

A1) Relative amount of miscellaneous costs = $\frac{\text{Miscellaneous costs}}{\textit{Total maintenance costs}}$ x 100

A2) Correctness of notifications = $\frac{\textit{Correctly filled in notifications}}{\textit{Total notifications}}$ x 100

A1) The miscellaneous costs can be determined by subtracting all correctly labeled costs, such as labor cost, from the total maintenance costs. A high percentage outcome indicates that many costs are not correctly labeled, decreasing the understanding in the maintenance expenses. The maintenance manager is responsible for both the maintenance budget and the labeling of costs, he is therefore responsible for this KPI. If progress on this indicator is lacking, the maintenance manager must give these accounting responsibilities a higher priority. A point can be made to shift these responsibilities to a maintenance assistant for example, if a higher priority is not possible.

A2) Notifications are essential for gaining insight in the expenses of each job. During the implementation of TPM, the maintenance manager uses this KPI to monitor the correctness of the notifications. The planning maintenance team is responsible for the notifications. The notification is considered correct if all the necessary fields in the ERP system are filled in, notifications where additional costs were added afterwards are excluded. Aiming for a high correctness rate is advisable, with the option to train the maintenance planning team if necessary.

5.3.2 Make the transition to preventive maintenance.

As mentioned in 5.2.2, the reliability of machinery can be improved by implementing preventive maintenance. The transition from corrective maintenance to preventive maintenance poses a challenge since each preventive maintenance task added creates additional workload, as corrective maintenance tasks will continue to appear due to the state of machinery resulting from years of corrective maintenance. To track the advancement in preventive maintenance, the following key performance indicator is placed:

B1) Portion of preventive maintenance jobs = $\frac{\textit{Preventive maintenance jobs}}{\textit{Total maintenance jobs}}$ x 100

B1) Without reliability centered maintenance a company can strive for a percentage as high as 60% with the use of TPM and Lean maintenance, according to Lean maintenance (Smith & Hawkins, 2004). For company X, this is not a realistic goal during the transition. Starting to track this KPI and gradually increase the portion of preventive maintenance jobs is a more realistic approach. If the portion does not increase, or even decreases, the probable cause is discussed. A drop in preventive maintenance jobs is acceptable in a week with an overload of breakdowns but signals a potential lack of persuasion by the maintenance department if an acceptable cause is lacking.

5.3.3 Teach the production team to fulfill their maintenance responsibilities

To monitor the progress on the objective of teaching the production team to fulfill their maintenance responsibilities, multiple key performance indicators are necessary to cover their responsibilities. While tracking the progress on being the eyes of the maintenance team can be difficult, key performance indicators can be selected for the responsibilities regarding notifications and basic maintenance tasks.

C1) Percentage of notifications the first-time right = $\frac{\text{Approved notificiations}}{\text{Total notifications submitted}}$ *x 100*

C2) # of notifications submitted for jobs that are considered basic maintenance
C3) # of jobs communicated without the use of notifications

C1) This percentage indicates the knowledge of the foremen about the writing of correct notifications. The maintenance planner, who acts as gatekeeper, decides if a notification is correct, as mentioned in 4.2.2. Missing information, a notification about a job that does not add value, or a notification about a problem that does not fall under the responsibility of the maintenance department are reasons to reject a notification. If the maintenance planner rejects a notification, the reason for the rejection must be attached. The planning maintenance team cannot prepare a job without the required information, this must be emphasized to the production department. Judging the value of a job, however, can be tough for the foremen, especially during the implementation phase. Therefore, trying to improve on previous scores and providing feedback to the foremen is advisable. Eventually, the aim for the first-time right percentage can be as high as 95% to reduce rework and ambiguity.

C2) The number of notifications that are rejected for being the responsibility of the production team is tracked separately with this indicator. The division between basic maintenance and the maintenance job must be clear to both the production team and the engineers. The maintenance planner flags every job he assumes to be a basic maintenance task. If the member of the production team does not agree, the case will be discussed at the weekly meeting between the production- and maintenance team (section 5.4.). As the members of the production team gain experience with their role, the number of basic maintenance jobs submitted to the maintenance team is likely to reduce.

C3) As stressed during this chapter, notifications are crucial for the effectiveness of the proposed measures in this report. Therefore, calling an engineer to report a malfunction instead of submitting a notification is only acceptable in an emergency. Explaining how writing a notification will lead to improved reliability of machinery can help to keep the production team motivated.

5.3.4 Develop affinity with the work methods associated with total productive maintenance

Gaining affinity with the total productive maintenance team roles and the *work order protocol* is a challenge that can be tracked by multiple key performance indicators. By using indicators that track the ratio of planned work, the availability and correctness of job plans, and the wrench time, the progress can be monitored.

D1) *Ratio of planned work =* $\frac{\textit{Planned work orders}}{\textit{All work orders}}$

D2) *Job plan availability =* $\frac{\textit{Work order with job plan available}}{\textit{All planned work orders}}$ *x 100*

D3) *Job plan correctness =* $\frac{\textit{Work orders completed according to job plan}}{\textit{Work orders with available job plan}}$ *x 100*

D4) *Wrench time =* $\frac{\textit{Time spent working with tools during a shift}}{\textit{The time of the shift}}$ *x 100*

D1) Planning a job is a crucial step in the work order protocol and therefore essential for the integration of the proposed measures presented in this report. Both the preventive- and corrective maintenance jobs can be planned. According to Smith & Hawkins (Lean maintenance, 2004), a company that adopts TPM must aim for a ratio of 0.95. In the case of an emergency, bypassing the *work order protocol* is acceptable. Planning work orders is the key responsibility of the maintenance planning team, and this key performance indicator is tracked by the maintenance manager.

D2) Job plans are not used in the current situation, thus are introduced during the implementation phase. For each work order, a job plan needs to be designed by the planning maintenance team. A job plan can be created by using manuals included by the supplier, the experience of the engineers, or job plans that are used for similar work orders. As more jobs are being planned, the job plan availability is likely to improve.

D3) A high job availability is especially helpful if the job plans are correctly written. A job plan is insufficient if the problem is not resolved, the prepared maintenance kit proved to be incomplete, or the time estimation was not realistic. By tracking this indicator, trends can be discovered and resolved. For example, constant underestimation of the time needed for a job can be noticed and discussed with the planning maintenance team. After the job notification is completed and submitted, the maintenance planner can get a drop-down menu in the ERP system that is used to select if there was a job plan available, and if so, if the job plan was sufficient.

D4) Eliminating time waste is an outcome of utilizing total productive maintenance with the *work order protocol*. Tracking the wrench time, the time an engineer is actually working with tools, can help to keep the maintenance department motivated, by showing the increase of productivity. The focus of using wrench time as a key performance indicator is to locate bottlenecks in the process and is not used as a supervising tool to check the performance of individual engineers. A wrench time between 55 and 65 percent is considered world class (Smith & Hawkins, 2004). Prior to the implementation, the maintenance department can measure the current wrench time as a baseline. If the wrench time is not increasing, and is still below the 55%, possible causes can be discussed with the engineers to potentially locate bottlenecks.

5.3.5 Prevent accidents by using the work order protocol

Executing work by following job plans can improve the safety at company X, since the production line will be idle and prepared for the engineer. To ensure the safety of personnel, the key performance indicators signal each potential risk to keep improving on this objective.

E1) # of times a jobsite is not prepared correctly (Missing permits, not complying to safety protocols, active machinery)

E2) # of (potential) injuries

E1) Preparing a jobsite is not only important for efficiency, but also a great way to reduce occupational accidents in the production company. The maintenance planning team is responsible for acquiring the necessary permits and the communication of the safety protocol. The production department is responsible for a prepared jobsite. When the job is not prepared correctly, the maintenance manager evaluates the situation and has a discussion with the responsible party to emphasize why it is crucial to prepare the jobsite.

E2) If, despite complying to safety protocols, an occupational accident occurs or was just avoided by luck, the maintenance manager must evaluate the situation with the maintenance department. Expanding safety protocols or taking drastic measures can help to prevent a hazardous situation from recurring.

5.3.6 Monitor the implementation of total productive maintenance

As mentioned in section 5.2.4, the monitoring of the implementation of total productive maintenance is a special objective. The key performance indicators that cover this objective focus on the vendor managed inventory, the work order discipline, and the overall equipment effectiveness (OEE). The OEE is used to measure the performance of TPM (Smith & Hawkins, 2004) and therefore receives an extensive description in this section.

F1) Overall equipment effectiveness = $Equipment\ availability \times Performance\ efficiency \times Rate\ of\ quality$

F2) *Service level of vendor managed inventory =* $\frac{Demanded\ parts\ available}{Total\ demanded\ parts}$ *x 100*

F3) *Work order discipline =* $\frac{Working\ hours\ accounted\ for\ on\ work\ orders}{Total\ working\ hours}$ *x 100*

F1) Overall equipment effectiveness (OEE) is a key performance indicator to measure the performance of total productive maintenance. OEE gives insight in the losses that TPM tries to prevent.

$$OEE = Equipment\ availability\ \times Performance\ efficiency\ \times Rate\ of\ quality$$

$$Equipment\ availabilit = \frac{Actual\ production\ time}{Planned\ production\ time}$$

$$Performance\ efficiency = \frac{Actual\ production}{Theoretical\ production}$$

$$Rate\ of\ quality = \frac{Good\ products}{Product\ output}$$

As mentioned in the definition of TPM, the aim is to increase the value of OEE. The gaps between the actual and theoretical outputs in the equations are the losses. There are 11 major areas of loss in four categories (Smith & Hawkins, 2004):

Planned shutdown losses:
1. No production, breaks, and/or shift changes
2. Planned maintenance

Downtime losses:
3. Equipment failure or breakdowns
4. Setups and changeovers
5. Tooling or part changes
6. Start-up and adjustment

Performance efficiency losses:
7. Minor stops (less than six minutes)
8. Reduced speed or cycle time

Quality losses:
9. Scrap product/output
10. Defects or rework
11. Yield or process transition losses

The planned shutdown losses are not used in the calculation of OEE, yet it is mentioned since it is hidden capacity for production. Using OEE, company X can identify areas with high losses to help set priorities.

F2) When outsourcing spare parts management, agreements are made to ensure a certain level of security. Although the supplier tracks its performance, the maintenance manager can monitor the performance on certain aspects for verification. For example, if the availability of parts has a high priority for the maintenance manager, he can select indicators that track the service level.

F3) This key performance indicator tracks the ratio of labor that is accounted for on work orders. This is important for the correctness of the notifications. Hours that are not attributed to specific jobs are a threat to the accuracy of the cost of a job. A low work order discipline can also indicate a lack of commitment by the planning maintenance team. Having a conversation with the engineers of the planning maintenance team about the necessity of writing correct notifications is advisable if this is the case.

5.3.7 The filled in TPM implementation grid for company X

For each selected key performance indicator, the corresponding indicator level must be determined prior to filling in the TPM implementation grid. Typically, indicator level 1 is appointed to comprehensive KPIs that are of concern to higher management, total maintenance cost for example. The KPIs with indicator level 2 are more detailed and more of concern to the maintenance manager, the relative amount of miscellaneous costs for example. While the KPIs with indicator level 3 are also of concern to the maintenance manager, these KPIs directly relate to the performance of the employees or other assets. By using these criteria, each selected KPI for company X can be assigned to the corresponding indicator level. Additionally, the indicator levels are used in section 5.4, to determine the frequency in which KPIs are reviewed.

Table 5.2: TPM implementation grid for company X

Objective \ Indicator level	Level 1: Production plant	Level 2: Production line	Level 3: Asset
Gain insight in the maintenance expenses		A1	A2
Make the transition to preventive maintenance		B1	
Teach the production team to fulfill their maintenance responsibilities			C1 C2 C3
Develop affinity with the work methods associated with TPM		D1 D2 D3	D4
Prevent accidents by using the work order protocol	E2		E1
Monitor the implementation of TPM	F1	F2	F3

A1) Relative amount of miscellaneous costs
A2) Correctness of notifications
B1) Portion of preventive maintenance jobs
C1) Percentage of notifications the first-time right
C2) # of notifications submitted for jobs that are considered basic maintenance
C3) # of jobs communicated without the use of notifications
D1) Ratio of planned work
D2) Job plan availability
D3) Job plan correctness
D4) Wrench time
E1) # of times a jobsite is not prepared correctly
E2) # of (potential) injuries
F1) Overall equipment effectiveness
F2) Service level of vendor managed inventory
F3) Work order discipline

Concluding, the key performance indicators that track the progress on the objectives mentioned in section 5.2 are selected and assigned to an indicator level, creating the TPM implementation grid for company X, as shown in table 5.2.

5.4 Monitoring the selected key performance indicators

The key performance indicators selected in section 5.3 track the progress on the TPM implementation objectives. The purpose of this section is to advise the maintenance manager on monitoring and evaluating these KPIs.

While the TPM implementation grid is helpful to ensure a balance in maintenance objectives, it is not a performance measurement system. The values of the key performance indicators alone are insufficient to act upon. Using a dashboard, as discussed in section 3.3.4, the maintenance manager can monitor the key performance indicators against his targets in real-time. The dashboard must be simple and appealing, so the number of KPIs on the dashboard is to be restricted. For example, tracking the relative amount of miscellaneous costs in real time does not add value, while a drop in the percentage of notifications the first-time right provides the opportunity to give feedback to the foreman on duty. Since the requirement of being simple and appealing is subjective, the maintenance manager ultimately decides how many KPIs are displayed on the dashboard.

An example of how the maintenance manager can use the dashboard to manage a KPI is displayed in figure 5. In this example, the maintenance manager tracks the percentage of notifications that are accepted the first time around. The maintenance manager aims for a percentage of at least 75%, yet there are red scores on his dashboard. He discovers a pattern, somehow notifications are being rejected in the morning shifts on Tuesdays and Thursdays. The maintenance manager opens some rejected notifications and find they are all send by operator Paul. He can now approach Paul to clarify how Paul can write better notifications, and why it is important to do so.

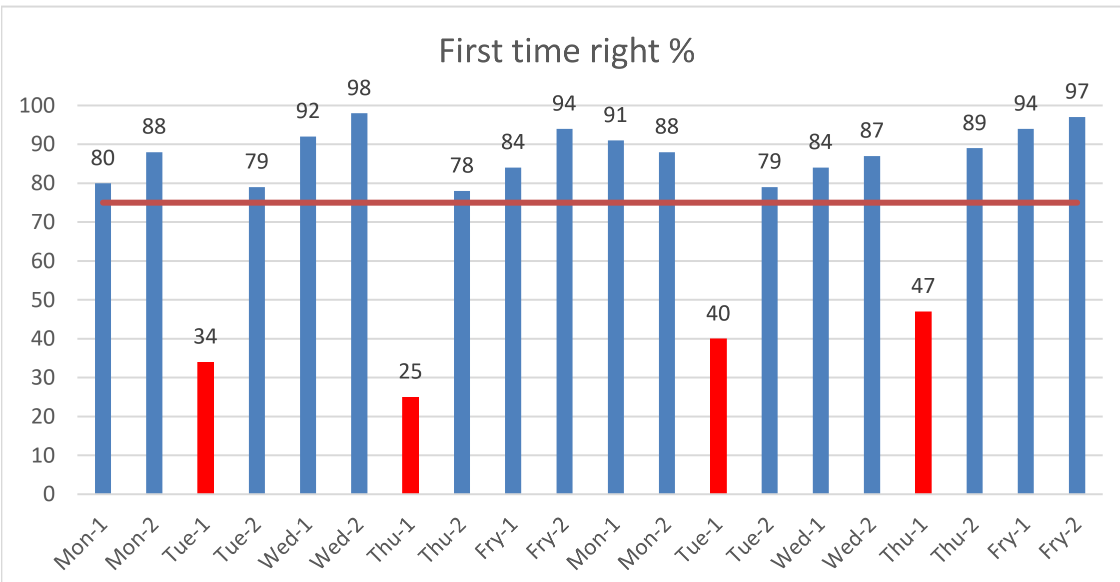


Figure 3.1: Example of a chart on a dashboard

The values of the KPIs are used as input in the review meetings. The review meetings, not to be confused with the daily planning meetings discussed in section 2.3.3, are used to discuss challenges, performance, and possible improvements. The maintenance manager and the engineers discuss problems encountered during the shift daily. Each week, the maintenance manager, the production manager, the planning maintenance team, and the foremen gather to review the performance of the past week. Potential quarrels over the division between responsibilities can also be discussed during this review meeting. At the end of the month, the maintenance manager, the director of the production department, and the engineers have a strategic review meeting, including observations from the engineers on the work order protocol.

The indicator levels discussed in section 5.3.7 are useful as a guideline for the review period. The KPIs with indicator level 3 are discussed during the weekly meetings since they track the performance of both the maintenance and production department. A drop in performance can be tracked back to either an incident or to a staff member: this is helpful to either prevent recurrence or to offer additional training. The KPIs of level 1 and 2 are reviewed monthly, since they are, generally, less influenced by incidents and track the strategic elements of total productive maintenance.

To conclude, the maintenance manager has the ability to act upon the key performance indicators in real-time by using a KPI dashboard as a visual monitoring system. The progress made on the maintenance objectives is used as input in the daily, weekly, and monthly meetings with the responsible parties.

5.5 Conclusion

This chapter introduces performance management for the maintenance department at company X by answering the following research question:

How can performance management be used to monitor the transition to preventive maintenance at the maintenance department of company X?

As discussed in section 3.3, the strategy of a company or department determines which key performance indicators are managed. The implementation of performance management has four steps:

1. Identifying and combining internal- and external influences into a strategy
2. Selecting objectives for this strategy for each perspective from the maintenance balanced scorecard (section 3.3.3)
3. Selecting key performance indicators that measure the progress on each objective
4. Monitoring and managing the key performance indicators

For the maintenance department of company X, the strategy proposed during this report is to implement total productive maintenance with *the work order protocol* and vendor managed inventory. This strategy, elaborated in Chapter 4, has the potential to increase the control within the maintenance department, the reliability of machinery, and the overall effectiveness, while reducing (time) waste and frustration between departments. This strategy does not conflict with the internal and external influences on company X as discussed in section 5.1. On the contrary, the internal influencing parties potentially benefit from this strategy.

The objectives for the implementation of this strategy are selected in section 5.2, utilizing the total productive maintenance perspectives presented in section 3.3.3. To implement this strategy, the following objectives are chosen:

- Gain insight in the maintenance expenses
- Make the transition to preventive maintenance

- Teach the production to fulfill their maintenance responsibilities
- Develop affinity with the work methods associated with TPM
- Prevent accidents by using the *work order protocol*
- Monitor the implementation of TPM

The chosen objectives are used in the TPM implementation grid, displayed above in table 5.2. The key performance indicators to track the progress on each objective are selected in section 5.3. Combined with an indicator level, the key performance indicators are put in the TPM implementation grid.

The progress made on the maintenance objectives is used as input in the daily, weekly, and monthly meetings with the responsible parties. The maintenance manager has the ability to oversee the KPIs in real-time by using a maintenance dashboard.

6. Conclusion and recommendations

This chapter contains the conclusion, the discussion, and further recommendations for company X. Section 6.1 provides the answer to the main research question, as stated in section 1.3.1, supported by the answers to the research questions that are answered throughout the report. Section 6.2 contains a discussion on the applicability of the solutions to other companies. Section 6.3 provides suggestions for the maintenance manager after total productive maintenance is successfully implemented. Further research is recommended in section 6.4. In section 6.5, the practical contribution is described.

6.1 Conclusion

Due to increasingly high maintenance costs at company X that are caused by the current maintenance procedures, the maintenance manager wants to adopt a new, preventive, maintenance policy. Since a new maintenance policy impacts the way engineers do their jobs, performance management is needed to guide the implementation process while keeping the approval of the engineers. Thus, for this research, the aim is to answer the following question:

How can performance management contribute to the implementation of a preventive maintenance policy at the technical department of company X?

To answer this research question, the current procedures within the maintenance department are analyzed. The maintenance department is divided over three locations, where engineers repair machinery when a breakdown occurs. The usage of the ERP system, that can generate periodic preventive maintenance tasks and can be used to process work orders, is limited to incomplete notifications about malfunctions. The high costs of the maintenance department are co-caused by a lacking purchasing- and warehousing policy.

To answer the research question, a literature study is conducted to make elements of the research question more specific. Total productive maintenance has the highest potential of the preventive maintenance approaches for company X. Outsourcing spare parts management by using vendor-managed inventory results in a workload reduction, so the maintenance department can focus on the implementation process of total productive maintenance. Performance management can be implemented by translating strategy into key performance indicators that track the progress on the maintenance objectives.

To implement total productive maintenance at company X, the organizational structure of the maintenance department is changed by introducing maintenance roles for the engineers. Combined with participation in maintenance by the production team, this organizational structure supports the implementation of total productive maintenance. The work order protocol, supported by standardized notifications, is used to eliminate waste at each step of the work order process, by improving the planning and scheduling of jobs.

Performance management can contribute to the implementation of total productive maintenance at the maintenance department of company X by using key performance indicators that are selected to monitor the maintenance objectives for the maintenance department at company X. The selected key performance indicators are presented in the TPM implementation grid and are used as input for review meetings between various stakeholders and aim for continuous improvement.

6.2 Discussion

The suggestions provided in the conclusion are first and foremost made for the maintenance department of company X. This discussion is included to question to what extent the suggestions can be used for other companies. In our opinion, there are five areas of discussion:

Selecting total production maintenance

In the trade-off between potential maintenance approaches, total productive maintenance was selected. For the trade-off, the following limitations were considered:

- *Lack of reliable data*: many proactive maintenance approaches rely on reliable data to predict upcoming malfunctions, TPM included. The argument that elements of TPM could be introduced while data is gathered favored TPM in this situation.
- *Limited resources:* without limited funds, a company could decide to equip all machinery with sensors. This way, each anomaly is immediately detected, and potential breakdowns can be prevented.
- *No prior experience with preventive maintenance*: as mentioned in the literature study, Lean maintenance is an improvement over TPM, but relies heavily on experience with TPM.

For a company that makes the transition from reactive maintenance to preventive maintenance, TPM is a good contender since it is relatively easy to adopt, data is continuously gathered, and the company has the long-term option to eventually improve to a lean maintenance approach.

Outsourcing spare parts management

In the literature study, the outsourcing of the purchasing and warehousing of spare parts is selected for company X. Again, a lack of data prevented alternatives for the short-term since the expected demand is unknown for the maintenance manager. Utilizing vendor-managed inventory has multiple advantages if the supplier is obliged to use the ERP-system of company X:

i) Data on the usage of parts is gathered, this can be used if the maintenance manager decides to insource the purchasing and warehousing in the future.
ii) The layout of the warehouse is likely to change to ensure spare parts have a dedicated location, making it easier for engineers to gather resources.
iii) The maintenance manager can focus on implementing TPM, instead of worrying about spare parts management.
iv) Engineers are not disturbed by multiple delivery vans each day.

For company X, the lack of purchasing and warehousing policies caused high uncertainty and high costs. If a company has functional policies in place, it is not necessary to outsource the management of spare parts.

<u>Structure of the maintenance department that supports total productive maintenance</u>
How engineers are distributed across the total productive maintenance roles relies on the initial structure of a maintenance department. The factors that determine the distribution are based on how many locations, how many engineers, the workload on each location, and the specialties of the engineers.

<u>Work order protocol</u>
The work order protocol has the potential to function for each company that has the same work order process. If a company has an extensive maintenance department, some responsibilities can be distributed to further the efficiency. Combining the roles of gatekeeper, storage clerk, and maintenance planner, as is the case for engineers of the planning team of company X, is far from ideal. Having both a specialized storage clerk that is responsible for the collection and return of spare parts, and a specialized gatekeeper that is responsible for the approval of work orders and assigns the appropriate priority level to each job will improve the workflow considerably.

<u>The selection of key performance indicators</u>
The key performance indicators that are selected for the implementation of total productive maintenance at the maintenance department of company X can be used by other companies. However, the selected KPIs are the result of a process in which the strategy of the maintenance department is translated into objectives. The strategy, and thus the objectives, is likely to differ from one company to another. For example, since company X is a dairy producer, and engineers need to disinfect themselves and the equipment each time they enter the production hall, having a correct job plan is important to reduce travel time. Having a correct prediction of spare parts usage is less important for an engineer that can complete a job inside the workshop next to the warehouse.

From these five areas of discussion, it can be deduced that the suggestions provided in this report cannot be described as ‘one size fits all’ solutions. However, a maintenance manager that aims to transform the maintenance department from a reactive- to preventive maintenance department can use the framework of the work order protocol and the selection process of key performance indicators to create a customized TPM implementation grid.

6.3 Recommendations

With the suggestions provided in this report, the maintenance department can start the implementation of total productive maintenance. In addition to these suggestions, this section contains recommendations on how to gain support of the stakeholders and what to do after TPM is implemented.

To implement total productive maintenance, it is crucial to gain and keep the support of all stakeholders. A good way to gain support for TPM is to illustrate how TPM can benefit both the maintenance- and production department. This can be done with a serious game, where teams of engineers, managers, and foremen of production work together to repair a certain item in different scenarios. The first scenario mimics the current situation, where an incomplete notification is written, job plans are unavailable, and spare parts and specialized equipment is missing, so this repair is destined to fail. In the second scenario, a notification is written according to the standard and all equipment is available, but the team still must come up with a plan and must locate all the equipment, resulting in slow but successful repair. In the final scenario the team is set up for success, a maintenance kit is provided, complete with checklist and all required materials. Hopefully, after experiencing how efficient TPM can be in practice, the willingness to invest time and effort into the implementation has increased.

After the implementation phase of total productive maintenance is over, the maintenance manager can opt for key performance indicators that fit the new objectives. For this phase, the four objectives presented in the TPM indicator grid of section 3.3.3 can be used. Most of the key performance indicators used in the implementation phase can still be monitored but are likely to relocate to the "Managing total productive maintenance" objective. Examples of key performance indicators can be found in the references used in section 3.3.3, but should only be selected if they can be aligned with the strategy of the maintenance department of company X.

In our opinion, the suggestions provided in this report complement each other and are therefore best implemented together. For example, if only the notifications are implemented without the TPM roles, engineers that are potentially covered in oil and are needed for another work order must complete a notification, likely creating a messy keyboard or rushing the notification. Similarly, implementing TPM with the current spare parts management can create demotivating situations and additional workload, both critical during the implementation.

6.4 Recommendations for future research

Potential topics of future research are encountered during the research at company X. While this report suggests feasible alternatives that support the implementation of TPM at the maintenance department of company X, future research can support improvement of the maintenance department after TPM is implemented.

Purchasing policy

The purchasing of spare parts is a topic for future research. The purchasing of spare parts is discussed in section 3.2.2, with vendor managed inventory as the preferred solution for the implementation of a preventive maintenance plan. This approach was preferred since it is an improvement of the current purchasing method while it outsources a time-consuming aspect of maintenance management, a welcome benefit during the implementation of TPM.

This is not likely to be the optimal solution in the long-term, however. Spare parts consumption data is collected using notifications, this data can be the input for further research into the purchasing of spare parts.

Warehousing of spare parts

Similar to purchasing policy, the topic of warehousing of spare parts is discussed in the literature study. In section 3.2.1, the use of a combination matrix for the warehousing of spare parts is discussed prior to the decision to outsource spare parts management. If company X prefers to be responsible for the management of spare parts inventory, research can be devoted to the implementation of the combination matrix since it requires the function and the production impact of each spare part. During research devoted to the warehousing of spare parts, promising alternatives to the use of a combination matrix can be explored.

Creating a prioritization matrix

The gatekeeping step in the work order procedure is discussed in section 4.2.2. This section suggests implementing a prioritization matrix to help determine the priority level of a suggested job. This prioritization matrix takes the possibility of an event and the impact of an invent into account to determine the time interval in which the job must be completed. The planning engineer can estimate the priority of a job based on experience and consult of the maintenance manager, but a structured prioritization matrix with guidelines is faster and can improve the accuracy. Creating a job prioritization matrix with concrete guidelines is therefore a potential topic for a thesis.

Lean maintenance

Lean maintenance, while being an improvement over TPM, cannot be implemented at company X in the current situation, as mentioned throughout section 3.1. If TPM is implemented successfully and the stakeholders are satisfied however, the implementation of lean maintenance can be considered. Since lean maintenance is more comprehensive than TPM, it is likely to affect more aspects of the production process. The implementation of lean maintenance is therefore a comprehensive research topic, yet a promising topic for future research.

6.5 Contribution to practice

The research conducted for company X supports the implementation of a preventive maintenance approach for the maintenance department while introducing performance management to control this implementation. This report contains insights in, among other things, the work order protocol and the TPM implementation grid. The work order protocol, with standardized notifications and TPM roles, provides the maintenance manager with a working method that embraces pro-active maintenance. The TPM implementation grid contains KPIs that track the process on the maintenance objectives of company X.

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