Better to prevent than regret

Gain insight in how to measure the performance of Bolletje's Technical Department to create a preventive maintenance plan.

Thijs Altena

Bolletje B.V.

16-5-2017

Bolletje

Author
T. (Thijs) Altena
Student number
s1236776

University
University of Twente
Master Program
Industrial Engineering & Management
Specialization
Production & Logistics Management

Graduate date
17-05-2017

Graduation Committee
Dr. Ir. A. Al Hanbali
First Supervisor
University of Twente

Dr. P. C. Schuur
Second Supervisor
University of Twente

Dhr. G. Leeftink
Company Supervisor
Manager Technical Department
Bolletje B.V.

"It is not possible to manage what you cannot control and you cannot control what you cannot measure!" (Peter Drucker)

Management Summary

This research is conducted at Bolletje as a Master thesis for the study Industrial Engineering & Management. The goal of Bolletje's Technical Department (TD) is to let all production lines produce as good as possible by conducting corrective and preventive maintenance in an optimal way. In the actual situation almost all available man hours are used for corrective maintenance. This results in less preventive maintenance, which causes more breakdowns and eventually even more corrective maintenance. Besides there is little insight in how the TD is performing regarding maintenance. This research is being conducted to transfer the corrective maintenance policy of the TD towards a preventive maintenance policy and therefore the main research question is:

"How can we create insight in the performance of the Technical Department by creating an environment where the activities of the Technical Department are measured properly to create a preventive maintenance plan?"

First the current situation is analyzed, whereby is concluded that the maintenance activity registration is incomplete and inaccurate. The registration in the logbook which is used to communicate throughout Bolletje's TD is very time consuming and does not create a database suitable for retrieval of accurate information based on machine, location, or timeframe. Due to a wrong usage of the information system for maintenance activities (called Rimses) it is impossible to keep up the actual inventory levels with as a result lots of 'stock-outs' and costly rush orders. Further, the TD does not have any kind of performance measurement besides the fact that they strive to keep all production lines 'up and running' while staying within budget. The Production Department (PD) does keep track of their performance with the help of an Overall Equipment Effectiveness (OEE) toolkit, but are not registering their production loss due to 'bad quality products' in the category quality, but in the category availability. This assumes that if the production lines create 'bad quality products' this limits the production lines availability, which is not true.

To create insight in the performance of the TD three Key Performance Indicators (KPIs) are selected:

- Production line availability
- Preventive maintenance time / Corrective maintenance time
- Mean Time To Repair (MTTR)

For the measurement of the KPI 'Production line availability' the OEE-toolkit of the production can be used, if the registration of the category 'quality' is used as it is meant in this toolkit. In that case the resulting percentage in the category 'availability' can be directly used as result for the 'Production line availability'-KPI. For the other KPIs, the information can be directly extracted from the Rimses database.

To improve the maintenance activity registration the following actions are proposed and implemented:

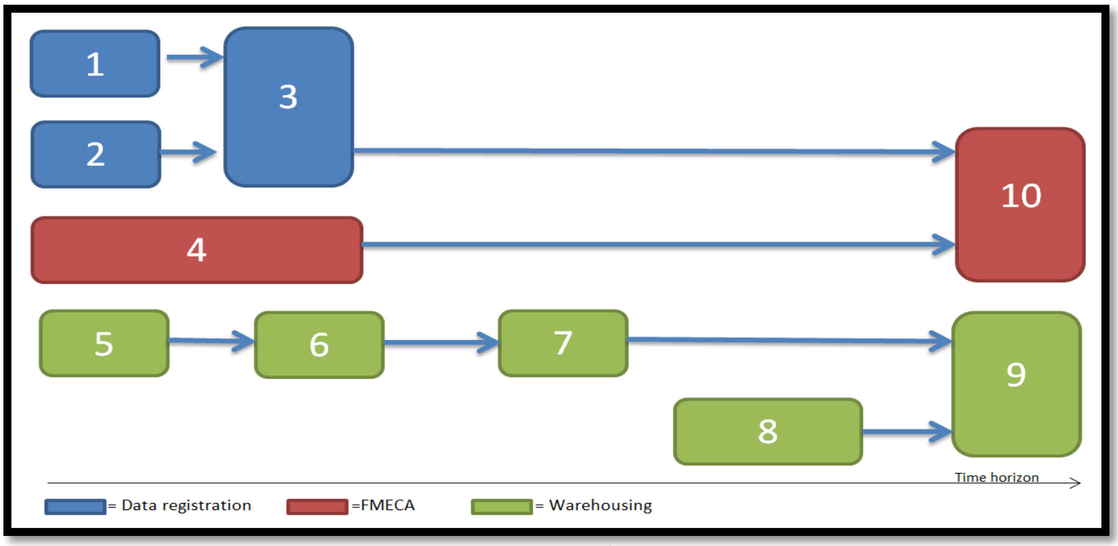
- Re-structure the 'Bill of Material' (BOM) of the machines in Rimses to improve logic and clarity. This is done by deepen the level of detail and by grouping comparable components.
- Control maintenance registration with the combination of the available Rimses-app and the PDAs with bar-code scanners to ease the registration process and stimulate complete and accurate registration.

- Automatically retrieve logbook (made in 'Report Manager') from Rimses database, which is collected with the registration using the Rimses-app.

To create an appropriate preventive maintenance plan all critical machines of the production lines need to be analyzed with the help of a method called Failure Modes, Effects and Criticality Analysis (FMECA). When this is executed, the result is a risk criticality determination for each possible failure cause of each possible failure mode. To decrease these risks the correct preventive maintenance action will be chosen on the basis of a maintenance policy decision tree. Within this tree there are eleven technical and economic questions which answers lead to the right maintenance action. The aggregation of all these maintenance actions will together form the eventual preventive maintenance plan. Which level of detail for every machine is included in the FMECA is done by the expertise of a maintenance engineer, a process engineer and the manager TD. Within this research FMECA was already performed on one part of a production line. Preventive actions which was never thought about in the TD organization (like inspection-instructions for operators and yearly checking of protection values) derived from the very first FMECA-session, which shows strength of a thorough method like FMECA.

Recommendations have been formulated in the form of a roadmap and a time schedule:

	Action	Actor
1.	Educate and supervise mechanics' registrations in Rimses-app on correctness and completeness of data.	Team leader
2.	Change the OEE-registration so that category 'quality' is used according to literature	Manager Production
3.	Display and monitor KPIs dashboard in Workshop	Team leader
4.	Execute FMECA for production lines: 61,353 and 350	Maintenance Engineer
5.	Set-up separation between 'registration of delivery' and 'invoice registration'	Master Thesis – student and Warehouse manager
6.	Educate TD organization about this new way of registration.	Master Thesis – student and Warehouse manager
7.	Re-determine stock levels and values (counting of current stock)	Warehouse-manager
8.	Classify spare parts according to classification method and select corresponding inventory control policy per class.	Master Thesis - student
9.	Process inventory control policy in Rimses	Warehouse-manager
10.	After a year, review FMECA: re-determine severity, occurrence and detection, with the data gathered with the Rimses-app as an extra input-variable	Maintenance Engineer



Preface

This report is the final result of my Master thesis conducted at Bolletje B.V. for the study Industrial Engineering and Management, track Production and Logistics Management.

This thesis would not have been possible without the help of others, who deserve acknowledgement for their support. First of all, I would like to thank Bolletje for giving me the opportunity for doing this research during six months within the Technical Department at the factory in Almelo. I would like to thank all my TD-colleagues, who welcomed me in their organization, made me feel comfortable from day one and always supported me with my research. Special thanks goes out to Gerrit Leeftink, who gave me the opportunity to do this research, let me free to do what I thought was best and stood 100% behind my choices, but above all offered me a great start of my career by hiring me as a process engineer at Bolletje.

Furthermore I would like to thank my first supervisor at the University of Twente, Ahmad Al Hanbali, for his guidance and for sharing his experience in the past six months. His interest and involvement in my Master Thesis allowed me to achieve this result. I sincerely appreciate the effort he took for giving feedback, which was very detailed and therewith very useful. I would also like to thank my second supervisor, Peter Schuur, for his valuable insight and critical feedback on my thesis.

Finally, I would like to thank family and friends who supported me, not only during my Master Thesis, but also during the rest of my study. A special thanks goes out to my girlfriend and my parents for their unconditional support throughout my entire study.

Thijs Altena

Almelo, May 2017

Table of contents

Abbreviations and definitions

FMECA	Failure Mode, Effects and Criticality Analysis
KPI	Key Performance Indicators
Maintenance Data	The result of registration of maintenance activities. (Data that is registered in Rimses and logbook)
MTTR	Mean Time to Repair
OEE	Overall Equipment Effectiveness
PD	Production Department
TD	Technical Department
TPM	Total Productive Maintenance
WO	Work Order

1. Introduction

This report is written to complete the Master of Industrial Engineering & Management with the specialization Production and Logistic Management at the University of Twente. This research has a time limit of six months and takes place at the factory of Bolletje in Almelo, within the Technical Department (TD).

In this chapter an overview of the research is shown. In section 1.1 there is an introduction of respectively the company, the factory and the department in which the research is being conducted. Secondly, in section 1.2 the necessity of the research is discussed. In section 1.3, the description of the problem is explained, followed by a resulting research objective in section 1.4. Finally the scope of the research and the research approach are presented respectively in section 1.5 and 1.6.

1.1. Bolletje b.v.

This section starts with a short introduction to the company Bolletje. First the origins of Bolletje will be described, then the factory in Almelo will be displayed, followed by a short description of the TD.

1.1.1. The origins

Gerardus Johannes ter Beek laid the foundation for the family company by opening a bakery with shop in the year 1867. This same company is known as 'Bolletje' since the fifties of the last century. His son Bernard started the specialization 'Beschuit' in the twenties. Beschuit doesn't have a direct translation into English, but is comparable with toasted bread, but crunchy and dry as a cracker and is always round in shape. In the thirties also Bernard's five sons and two daughters were included into the company (see Figure 1.1).

Figure 1.1: The Family Ter Beek (Bolletje B.V., sd)

The name Bolletje was introduced in the year 1952. A new name was invented, because the original name was *'Ter Beeks Eierbeschuit'* and the products were mainly sold at other bakeries who didn't like to sell products with a name of another bakery on the package. The new name was invented by Gerard and Jan (Bernard's sons), which walked past the production line and saw little balls of dough (in Dutch: 'Bolletje deeg') as seen in Figure 1.2, which form the basis of 'beschuit' and thought: *Kiek, doar he'j oewn naam!* (Look, there's your name!).

Figure 1.2: Balls of dough

In 1954 Bolletje moved to the current plant location at 'de Turfkade'. The bakery is turned into a factory. At that moment there were twenty different beschuit-producers in the Dutch market. Five years later Bolletje is the market leader.

Throughout the years Bolletje extended their assortment by adding products like ontbijtkoek (gingerbread), pretzels and roggebrood (rye bread).

In 1975 Bolletje took over *'Van Ark's bakkerijen b.v.'* in Heerde. With this takeover also the products cookies and biscuits were added to the list of products Bolletje produces. In 2009 Bolletje added the latest new product: knäckebröd. (Bolletje B.V.)

1.1.2. The factory in Almelo

Figure 1.3: Production line 'Lijn 6' in section 'Oude Beschuit'

The factory consists of four different production sections. Firstly there is a section 'oude beschuit', where the first original production machines from 1954 are still in operation (see Figure 1.3). In this section different kinds of beschuit are being produced on three different production lines. These production lines are during more than 60 years of existence developed to very stable lines, with a relative low failure rate. The disadvantage of these lines is that if a failure occurs, this often has a long duration with high costs, because spare parts are not always available and need to be self-fabricated, repaired or overhauled.

Then there is the second section called 'Banket'. Here are three banquet – lines where products like kruidnoten, schuddebuikjes and salty sticks are being produced. The production of these 'banket' – products is relatively simple, because it's simply preparing the dough and guiding it through the oven. The technical difficulty of these production lines is located more on the packaging side. The weighing of the products into the packages is a precise business, with advanced regulation systems with different steering techniques and many different sensors.

The third section is called "Roggebrood". This section consists of two rye-bread – lines. This is not a continuous flow of products like 'beschuiten' and 'kruidnoten', but is handled in batches. Batches of rye-bread are mixed, rested and baked in the oven. There are three ovens, and a maximum of 15 batches of rye-bread per week is possible. After the baking process the rye-bread will be cooled, sliced and packaged.

Figure 1.4: Production line 'Lijn 61' in 'Hal 16'

The last production section is called 'Hal 16' in which two knäckebröd-lines and one new beschuit-line are in operation. This hall was newly built in 2006. The first production line that was placed in 2007 was a knäckebröd line called 'lijn 350'. The other knäckebröd line called 'lijn 353' was placed together with the beschuit line called 'lijn 61' in 2010 (see

Figure 1.4). When the knäckebröd lines operate at full capacity in 24 hours 290,000 slices of knäckebröd are being produced on each line. The beschuit line can produce 100,000 rolls of beschuit in 24 hours at full capacity. One roll contains 13 beschuiten, which comes down to a total of 1,300,000 (!) beschuiten in 24 hours.

1.1.3. The Technical Department

As you can imagine, it is very important that there is as least as possible downtime, because production loss is very costly. The TD has a very important and leading role in this. The TD of Bolletje is responsible for the corrective and the preventive maintenance for the complete machinery at the factory of Bolletje in Almelo. The TD is carries out the following activities:

- Urgent failure solving (Corrective Maintenance)
- Long term failure solving (Corrective Maintenance)
- Inspections (Preventive Maintenance)
- Periodic maintenance (Preventive Maintenance)
- Production support (adjusting the machinery etc.)
- Modifications (redesigning current machines)
- Projects (purchasing new machines or production lines)

To perform all maintenance related activities a team of approximately 25 people is needed. Not to mention the external mechanics that are hired to execute either specialist work or hired as extra capacity during major preventive maintenance activities or disruptions. How the TD handles this responsibilities will be further discussed in chapter 2.

1.2. Research motivation

The overall goal of Bolletje in the coming years is to make sure that every production line can produce a high quality product, at a constant level without any major interruptions.

The goal of the TD is to let all production lines produce as good as possible by conducting corrective and preventive maintenance in an optimal way.

It is already clear that from the maintenance activities described in section 1.1.3 almost all available man hours are used for urgent failure solving (reactive maintenance). The only preventive maintenance that is being performed are so called ‘maintenance weeks’. For every production line one week per year is planned for periodic maintenance, where some standard maintenance activities are being performed. This research is being conducted to move the TD-organization towards a preventive maintenance environment.

1.3. Problem description

The problem the TD has is perfectly expressed in Figure 1.5. At this time Bolletje is circling in the vicious circle of reactive maintenance. Because the registration of maintenance data is not organized and accurate, the TD is not capable of learning from failure history of machines and his parts. This results in reacting to breakdowns, which costs time. Due to time limitation there is no time to register accurate data (or create an environment where this is possible). This results in insufficient knowledge for preventive maintenance. And if there is sufficient knowledge for preventive maintenance there is no time for it, because all man hours are used for the corrective maintenance, which has a higher priority, due to high costs regarding lost production.

That's why we want to break through this vicious circle in this research. We will achieve this by first organizing and registering the right maintenance information, so that we can react to breakdowns, and in the end can predict breakdowns and create a preventive maintenance plan. This preventive maintenance plan will ensure less time is needed for reacting to breakdowns, i.e., corrective maintenance, which also will lower maintenance costs dramatically, because corrective maintenance is very costly, as shown in Figure 1.6.

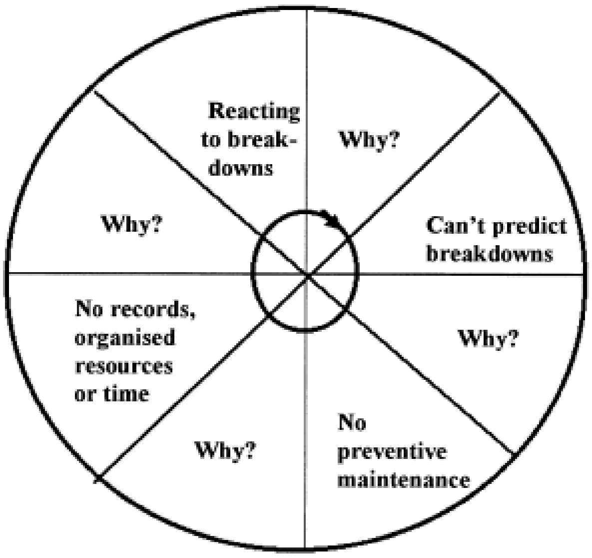


Figure 1.5: The vicious circle of reactive maintenance (Chand & Shirvani, 2000)

The main problem is the 'vicious circle of reactive maintenance', which starts with the inaccurate maintenance information gathering. There are several causes to identify for this problem:

- Communication and knowledge of the PD
- Registration of data

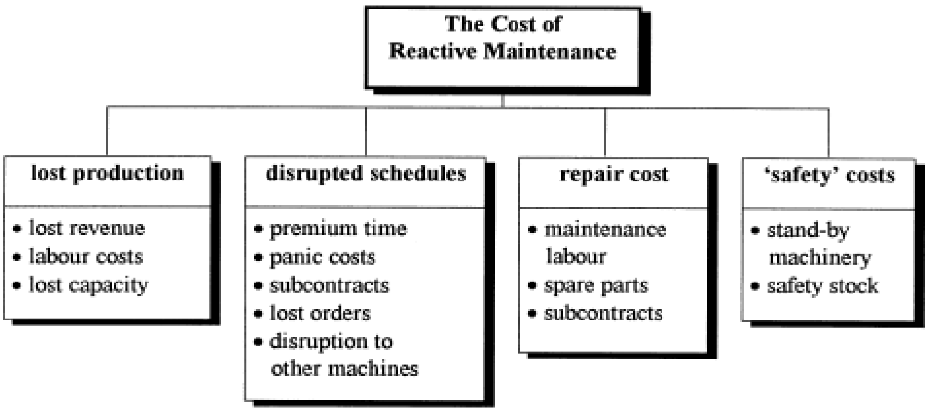


Figure 1.6: The real cost of reactive maintenance (Chand & Shirvani, 2000)

1.3.1. Communication and knowledge of the PD

Achieving a good production performance is interplay between the PD and the TD. Both departments are dependent on each other. The PD needs the TD to perform preventive and corrective maintenance to make sure the production can continue to operate. The TD needs the production to inform them with the right kind of information regarding failures, so these can be rectified as soon as possible. Cooperation is needed between both of them to share information and expertise.

The TD is not able to analyze failures continuous, the failure mechanics are called after the failures has occurred, that's why it is very important that the PD (who are able to constantly monitor the process) provides the TD with the right information regarding the failure. One might say, that the operators are the eyes for the mechanics. For example, if a packaging machine is not filling the boxes properly, it is important to inform the mechanics about cases like;

- What were the last adjustments to the machine?
- What failure signals did the operating system give?
- How often does the failure arise?
- Are there any other possible causes? Like usage of a different kind of packaging or an adjustment earlier in the line, which caused the product to change in size, or the like.

From interviews with the mechanics appears that this information is often very inaccurate. The operators present at the line have too little knowledge and ownership feeling to provide the mechanics with accurate information. A good example of lack of ownership is the fact that when the mechanics are busy with solving a failure, it is a natural habit that the operators see this as a good time for a cup of coffee in the canteen instead of learning from the mechanics and developing knowledge and ownership of that particular machine.

Further the PD is also responsible for assigning the work order which belongs to the failure to the right machine in the 'maintenance database program' called Rimses (this program will be examined in chapter 2). Due to the lack of knowledge and ownership this assigning is often inaccurate, because either the wrong machine is selected or the level of detail chosen is incorrect. For example, if a failure occurs at the machine which is responsible for the printing of the expiration date on the package, the failure is booked under the entire 'Packaging Department' instead, of specifying that it was the specific 'Expiration Date Printer'.

1.3.2. Registration of data in Rimses

As mentioned in the section above, registration of maintenance activities is often inaccurate due to lack of knowledge and ownership of the PD. But besides this, the registration within the responsibility of the TD leaves much to be desired. These problems concerning the registration of maintenance data will be briefly described below. Hereafter it will be further enhanced in chapter 2, where the current way of working of the TD is discussed.

Overview machine structure

The organization of the machine structure in the main overview in Rimses is the first part of the problem. The current machine structure is not complete, modifications to the machines are not updated and there is a lack of maintenance history at the right level of detail for specific parts. This detailed history is needed to analyze failure rates and suchlike at desired specification level.

Two different databases

The TD team leader has a morning meeting with the production leaders every day. In this meeting the daily results in terms of safety, quality and quantity are examined. Within this also the failures and points of interest for the TD are handled. From the TD's point of view this is done based on the data that is collected in an excel logbook.

Each work activity is registered in the main database for the TD called Rimses, but next to that also separate registered in the logbook Excel-sheet. The use of two different databases enhances the chance of inaccurate registration. Because it is labor-intensive and redundant the tendency of a hurried completion will be amplified. Data generated by hurried completion, and thus inaccurate registration is not reliable and therefore cannot be used properly to measure the performance of the TD.

Lack of accurate registration

To say something useful about components in the machine structure it is necessary to register the costs you make to keep that component running. These costs consists of both the man hours of mechanics as the costs of material. At this moment this is not the case because the time spent on each WO is roughly estimated or even not filled in at all. The reason for this is that the mechanics perform this at the end of their shifts, which ensures that most mechanics don't know how long each WO lasted. Further also the used materials are not registered correctly. The reason for this is that there are two different ways of registering materials; namely on paper and directly within Rimses. The half of the mechanics still does the registering on paper, whereby the warehouse manager it fills into Rimses, and half of the mechanics executes this action directly themselves in Rimses. This enlarges the lack of confusion and results in omitting of the process, because "It makes no sense whatsoever". Another reason for this confusion is the fact that there are no actual stock levels, which will be discussed below in 'spare parts management'.

Spare parts management

At this moment the inventory recording in Rimses is arranged as follows:

When a spare part which is ordered arrives at Bolletje, the part is physically put on stock. But in the system the part will not be registered and put on stock, because if the price that has been filled in with the ordering does not match with the eventual invoice amount the system will give an error, and it will be very difficult to restore this difference. To restore the difference it is namely necessary to let an ICT-specialist of Bolletje switch off a security which protects subsequent changes. To avoid this time-consuming activity, the warehouse manager simply waits till the invoice arrives (which is often a couple weeks, sometimes months later than the delivery of the part) before he registers the part and also puts the part on stock in the system.

This results in the following consequences:

- Never real-time stock quantities
- Often cases of ‘no stock’
- Which causes expensive ‘rush orders’

Concluding it can be said that the main problem for the vicious circle of reactive maintenance is the fact that no maintenance history at the right level of detail is created, due to the wrong or incomplete usage of the program Rimses, which in fact has all the requirements for preventive maintenance input. Of course eventual the right steps should be taken towards actually carrying out a preventive maintenance plan (think of methods like FMEA), but it all starts with the creating of a precise maintenance history.

1.4. Research objective

Based on the problem description in section 1.3, we can define the research objective in the following manner:

Research Goal: *Gain insight in how to measure the performance of the Technical Department to create a preventive maintenance plan.*

To reach this objective measurement of the performance needs to be created. This starts with sorting out the registration of data, i.e., which aspects of maintenance information is needed in which level of detail. When the right framework for this information is set and the information is gathered correctly, it will be very useful input for your preventive maintenance plan. It may be the case that there are other factors which obstruct effective preventive maintenance, like inaccurate spare part management or inefficient execution of tasks. If these problems arise, this will also be further examined. Depending on the complexity and time consumption of the problem it will be decided if this problem will be addressed within this research or this will be used as recommendation for further research.

1.5. Scope of research

Because the research is commissioned by the TD, this research is conducted from the view of the TD. This means that answering the main research question should mainly contribute to improvement of the performance of the TD.

The location Heerde could be used as a source of information, but the research is conducted at the location Almelo only, the location Heerde will be not taken into account.

Regarding the performance of the TD only the quantity of maintenance will be taken into account. The way maintenance is performed and what the qualitative result of the different kinds of maintenance is will be excluded for this research. The assumption is made that when maintenance is being executed that maximum quality is achieved. Further there is a limited time line of six months for this research.

1.6. Research approach

In order to create structure in this research six research questions will be formulated. These questions represent six phases of the research and the main chapters of this report. These six questions are used to answer the main research question, which is:

Main research question: *How can we create insight in the performance of the Technical Department by creating an environment where the activities of the Technical Department are measured properly to create a preventive maintenance plan?*

This research starts with an analysis of the current way of working. This is necessary to see the current state, so that from that point the path that has to be followed to improve the performance of the TD can be determined. This is stated in the following sub-question:

Sub-question 1: *What is the current way of working within the Technical Department of Bolletje?*

When the current situation is analyzed and described, a literature research is needed to find experiences regarding successful maintenance plans and methods. Hereby we want to examine at least how we can create performance measurement and how to create a preventive plan. This is expressed in the following sub-question:

Sub-question 2: *How should a Technical Department measure its performance and what is the best way to create a preventive maintenance plan according to literature?*

When the current situation and possible future situation from literature are known, it is time to create a plan how to get from the current situation towards the desired situation. This starts with creating insight in the performance of the TD. The first step in creating insight is translating the goal into measurable key performance indicators (KPIs). When these KPIs are defined, the data available within Bolletje can be researched to see if there is data usable to measure these KPIs. This results in sub-question 3:

Sub-question 3: *What Key Performance Indicators give a representative overview of the performance of the Technical Department?*

In advance the OEE statistics seems like a possible source of measurement for the KPIs. It needs to be researched how these numbers are created and if it is a reliable source as it stands or that an extra effort is needed to make it value-added. That's why sub-question 4 is formulated as follows:

Sub-question 4: *To what extent are the OEE figures used by the Production Department a reliable source for measurement of these KPI's?*

From sub-question 2 we will learn what the most optimal way should be to create a preventive plan. This also will create requirements of registration of maintenance data. At this moment it seems like that registration of maintenance data is not done in the most optimal way. That's why we want to research how the registration of maintenance activities should be executed, translated in sub-question 5:

Sub-question 5: *How should the registration of maintenance activities be organized so that it is value-added for making a preventive maintenance plan?*

Now that is known which maintenance information (and in which level of detail) is needed to create a preventive maintenance plan, we actually want to research how a preventive maintenance plan should be organized expressed in an action plan, which is expressed in the following sub-question:

Sub-question 6: *What steps should the TD follow towards a successful preventive maintenance plan?*

When these six questions are answered, also the main research question can be answered with as a result a recommendation for the TD of Bolletje. This conclusions and recommendations can be found in chapter 7.

2. Current situation

In this chapter the current situation of the Technical Department is explained in more detail by answering sub-question 1: *What is the current way of working within the Technical Department of Bolletje?*

Due to a reorganization there is need to clarify the 'old TD organization' and a 'new TD organization'. Further the procedures the TD follows regarding their maintenance registration and performance measurement will be explained.

2.1. Organization

2.1.1. Old organization

At the moment the research started the TD of Bolletje consisted of approximately 25 people. At the head of the department there is a TD manager.

Further there are:

- 6 failure Mechanics
- 2 Electrical technicians
- 2 Mechanical technicians
- 1 Lubricator
- 1 Painter
- Several temporarily workers
- 1 Warehouse manager
- 2 Maintenance engineers (project based)
- 2 Control engineers (programmers)
- 1 Planner
- 1 Project Engineer

The 6 failure mechanics work in three shifts. So in every shift there are 2 failure mechanics present. These mechanics are responsible for the urgent failures. The electrical and mechanical technicians, lubricator, painter and control engineers are responsible for the non-urgent maintenance activities. The maintenance engineers are responsible for the long-term maintenance planning and management of the 'periodic major maintenance' being executed on every production line once per year. The planner is responsible for the division of labor of non-urgent maintenance activities and the project engineer is involved in every project regarding major investment decisions. Think of decisions like the necessity of a new production line and what the best options to choose for are.

2.1.2. Future organization

In the first two weeks since the research started a lot of changes have been made in the TD organization. These changes had a large impact on the department. Unfortunately, there were two mechanics whose contracts had to be ended. Further there are functions that will expire in the long term and the responsibilities of different functions will change. Moreover the number of failure mechanics will increase from six to eight, which means that they will work in four shifts instead of three. The fourth shift is added, so that at daytime the capacity of failure mechanics is doubled.

These changes were made, because it is decided that more emphasis should be on tackling urgent failures directly, rather than on the long term. The focus of the TD is from now on the core business: corrective and preventive maintenance. The side issues are being outsourced, so that this can be deployed more dynamically. These changes lead to the organization chart shown in Figure 2.1.

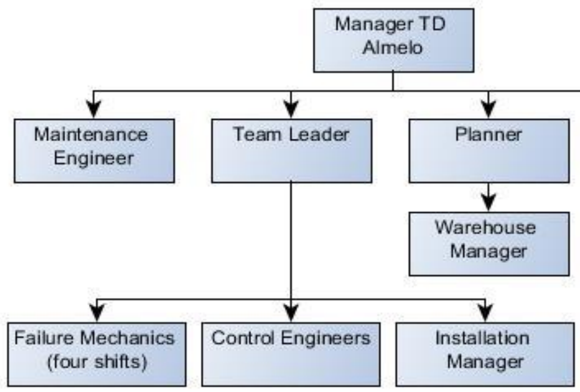


Figure 2.1: Organization chart Technical Department

Now that the organization is described we will continue with explore the current way of working of the TD.

2.2. Maintenance Data registration (Rimses)

In this section the current way of working regarding the maintenance data registration will be investigated. To create more understanding of how this works, this will be done based on an example. As an example the newest production line called 'Lijn 61' is chosen. This line is the production line which produces the main product of Bolletje, namely 'beschuiten'.

2.2.1. Overview Machine Structure

To use the program Rimses for what it's designed to do the first step is to make sure all components of your machinery are filled in completely and the structure in this overview is logical. Every maintenance activity is namely linked at components. This is obviously the case because you want to assign and divide the costs you make over the different components within your factory. As can be seen in Figure 2.2 at this moment the machine structure is not logical and incomplete. This is because for example when the WP-kneder is unfolded, only one replacement part is registered. Obviously the WP-kneder has much more parts then only a 'dichtungskopf'. The WP-kneder consists namely of for example an engine, a transmission, a pump and a helix. Not to mention all the bearings, seals and other smaller components. This incompleteness is the case for almost all components in 'lijn 61'.

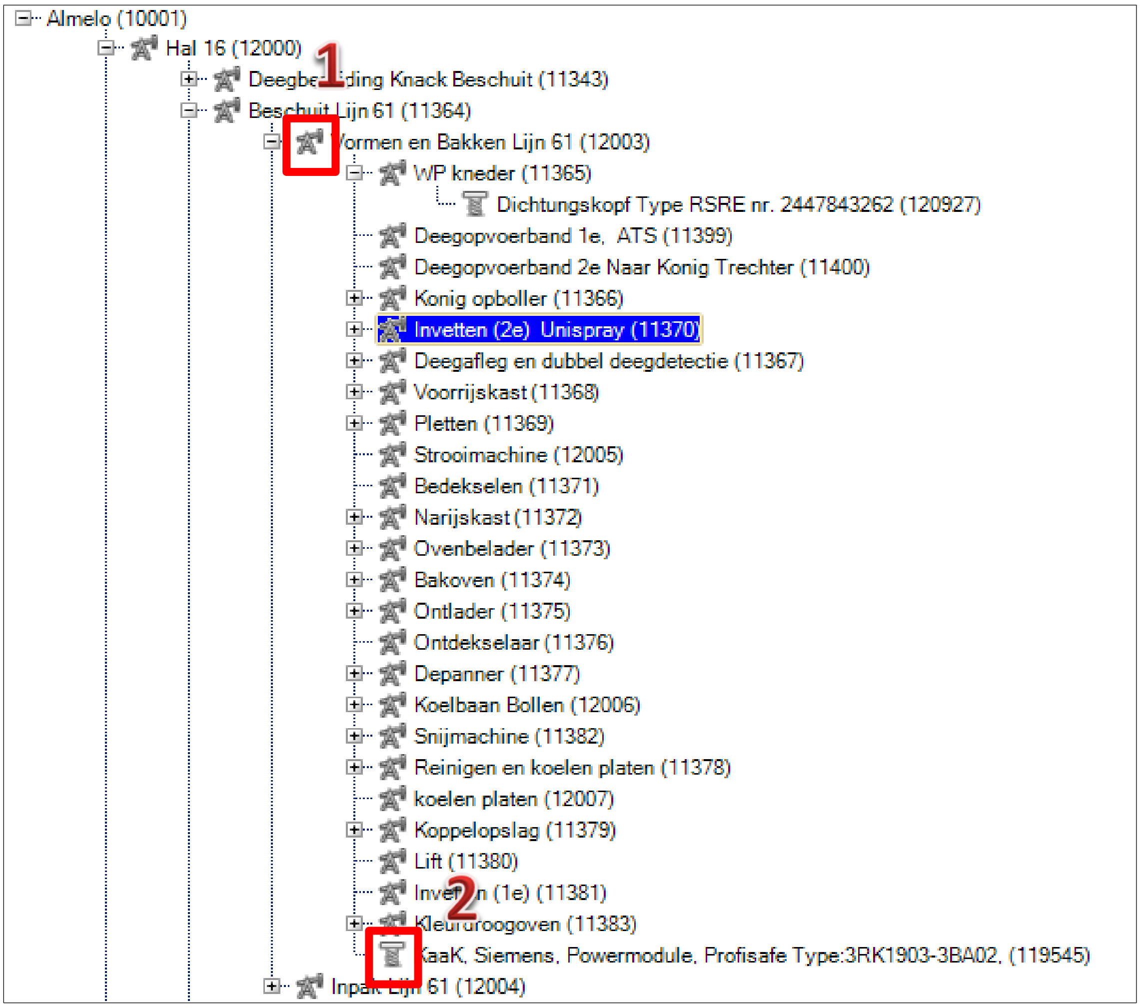


Figure 2.2: Part of Machine Structure in Rimses of 'Lijn 61' with production assets with a pump jack -icon (indication 1) and parts with a bolt-icon (indication 2).

Further, the overview structure is not logical. As can be seen at the bottom of Figure 2.2, there is one part (recognizable by the ‘bolt’-icon with indication 2) assigned to a sub-group, which is not possible, because ‘vormen en bakken’ is just a collective name for a part of the production line. These inconsistencies are present throughout the whole machine structure overview.

Further, it is not logical, because it is cluttered. For example, the sub-group ‘vormen en bakken lijn 61’ consists of 25 components. This represents the first 130 meters of the entire 200 meter production line. It would be way more logical to divide this group into smaller sub processes to create more clearness. This makes it easier to search when WO are assigned to machines, but also creates overall clearness and understanding of the production line and is thereby easier manageable by all employees.

2.2.1. Work Order Registration

The registration of maintenance activities within Bolletje can be divided into two categories: registration of urgent failures (Prio 1) and non-urgent maintenance activities (Prio 3). Prio 2 is present within the program, but this category gradually disappeared from the work environment. The prio 1 WOs are directly registered in the form of a WO, because this needs to be tackled right away, and the planning phase can be skipped. The prios 3 are registered in the form of a 'work request', which can be planned by the planner of the TD and turned into a 'work order' at the moment it can be performed. The prios 1 and 3 can be created by the TD, but mainly will be created by the production department (PD). The PD uses the sub-system of Rimses called E-Rimses to create WOs or work requests. This E-Rimses is a simplified display of the Rimses system, used to elementary let the production employees create WO's, without access to the system.

Urgent failure activities (Prios 1)

For the registration of the urgent failures the following path is followed:

1. When an operator encounters a failure which he/she cannot solve without the help of the TD, the failure mechanic is being called, where after the failure mechanic will come to help with the failure.
2. When the failure mechanic is on his way, the operator will create a WO in E-Rimses, and print a registration form with the WO-number on it on paper (see Figure 2.3).
3. The failure mechanic will carry out his repair.
4. When the failure is solved, the operator and the failure mechanic will both sign the paper and fill in what was the problem and how it is solved.
5. The mechanic will take the paper back to the workshop.
6. At the end of a shift, all papers are registered in Rimses by the TD. This is done by searching and selecting the WO number (which is generated by operator in E-Rimses) and filling each WO what was the cause, what has been done, which parts are used and what was the duration of the repair (which is often guessed and rounded to hours).
7. To meet auditing obligations regarding save and clean working all printed a4 pages are scanned and saved.

(Also see Appendix A-1: The flowchart for handling prio 1 WOs)

Plan maintenance activities (Prios 3)

The planner is responsible for the planning of personnel and dividing the different work requests (turned in to work orders) over the different mechanics. At this moment this is done by adding work orders to 'to-do-lists' of the mechanics. Planning with reference to date and time is not being executed.

(Also see Appendix A-2: The flowchart for handling prio 3 WOs) versie: Juli 2015

Bolletje

Rimses Begeleidingsdocument

(opdrachten prio 1 en 2)

Werkordernummer:	**Datum:**	**Lijn:**	**Machine:**
44077	24-1	21	oven

Oplevering van de uitgevoerde werkzaamheden:

Accoord voor oplevering	Naam	Datum	Paraaf
Opdrachtgever	John	24-1	
Opdrachtnemer	rutger		

Bevindingen monteur:

Oorzaak van de storing:

grille mat

Bestede uren:

Gebruikte materialen:

Origineel: Maintenance Engineer: Beheerschijf/begeleidingsdocumenten/orgineel/prio 1 en 2

Figure 2.3: Example of a printed prio 1 document with signatures of mechanic and production employee for completion of work.

2.2.2. Logbook

To communicate the maintenance activities throughout the TD organization an excel sheet is used (see Figure 2.4). This logbook is filled in a computer which is available in the TD-workshop. Within this logbook they note the date, shift type, WO number, production line, machine and what was wrong and/or what is fixed. As you may have noticed the use of this excel logbook is in fact double work, because first the activities are registered in Rimses, and afterwards actually the same information is filled in the excel logbook. Because it is labor-intensive and redundant the tendency of a hurried completion is amplified.

Logboek TD

Vroeg	Opmerkingen
Laat	
Nacht	
zaterdag	
Opmerking	
Vervolgactie	

Datum / Naam	Werkorder	Lijn	Machine	Omschrijving probleem / Oplossing
12-12-2016 GH & DOA				
	43221	353	breker	de breken onder de snarenband ging stil staan als er twee plakken knack in vielen slipkoppeling slipte deze straker gezet nu wel goed
	43222	61	depanner	cillinder voor opgaande beweging van uitzuigtafel is lek, cillinder gereviseerd. Nieuwe cillinder is besteld, oude is versleten.
	43211 43213	12/13	Checkweigher	bandje van 1e uitwerpband liep schokkerig, tanriem opgespannen
	43212	61	E-mark	emark starte niet op, sd kaartje was corrupt. Nieuwe sd-kaart gemaakt.
	43220	61	uitvoer, bakoven	wals van de uitvoerband van de oven is gebroken, wals uitgebouwd, nieuwe wals wordt gemaakt bij boesenkool, komt tegen 4 uur binnen
	43224	350	paneermeel installatie	afvoerworm achter de deegbaan was vast gelopen, worm zat vol met deeg, leeg gemaakt. Loopt nu weer goed.
	43223	61	konig, 1e spreidbandjes	spreidbandjes slipten, drukwalsjes zaten niet goed tegen de bandjes
		4	10 zaden apparaat	productie ondersteund bij het plaatsen van de banden

Week 48 | Week 49 | Week 50 | Week 51 | Week 52 | Week 53 | Blad1

Figure 2.4: Logbook of the TD

2.2.3. Inventory management

At this moment the TD has a problem with keeping track of the real-time stock quantities. This problem is mainly caused by the registration of receiving of parts. The current use of Rimses is configured in such way it is not possible to put a part 'on stock' in the system, if the invoice has not been received yet. When you register the ordered part as 'on stock' in Rimses, and the invoice (which often comes like months later than the delivery of the part) has another price value than registered, this can't be restored in the system, without the help of an ICT expert who needs to disable security systems. To avoid this problem, it is simply chosen to register the part as 'on stock' at the moment the invoice arrives. Which causes that you will never have real-time representation of your stock.

Example

To exemplify the fact described above an example of this case will be shown below:

- The warehouse manager orders six bearings at Monday 2 January, because they are out of stock. (Both physically in the warehouse and in the system the stock is zero.)
- The warehouse manager estimates that this will cost € 25,-.
- The delivery is done on Monday 9 January, but the invoice will arrive at Monday 6 February.
- At Monday 9 January the part will be physically put on stock in the warehouse, but not yet in the system, because the warehouse manager is not sure if the eventual invoice is € 25,-

Until the invoice arrives at Monday 6 February the stock quantity in Rimses will still be zero, despite the fact that there are actual six bearings physically on stock. In the meantime it is very likely that the mechanics use two bearings in January, so the actual stock quantity is 4. The mechanics cannot register this bearing within a WO, because the system shows stock quantity zero, and a negative stock is not possible.

When the invoice comes at 6 February, the warehouse manager can finally put the ordered bearings 'on stock' by registering the invoice. The invoice has a total costs of € 27,50, so the warehouse manager changes the estimated costs of the order to € 27,50 and puts the six total bearings on stock. Result: the system says that there are six bearings on stock, but in practice there are only four bearings left. In other words, the stock quantities are completely off track.

The fact that there are no real-time stocks has the following consequences:

- High risks of 'out-of-stock'
- Production loss due to waiting for parts
- Expensive rush-orders
- Risk of duplicate orders

2.3. The performance of the TD

As said in section 1.4 it is desirable to create some kind of performance measurement for the TD to monitor if improvements have their desired effect. That's why in this chapter we will investigate what sorts of performance measurement is present at this moment within the Bolletje organization.

2.3.1. Measurement of performance TD

At this moment the TD does not make use of any sort of resource to create insight in how they are actually performing. In the past a report is designed which shows automatically makes a list of the top 5 machines which caused the most problems. Unfortunately the report hardly ever has been used. Simply it can be said that the TD tries to keep the production lines 'up and running', with one restriction, namely stay within the budget. In other words, at the moment there is solely one KPI, namely 'stay within budget'. In section 4.1 we will investigate which KPIs can be identified for the TD.

The PD, on the other hand, does keep track of their performance, namely with the help of the improvement tool OEE. To see if this could also be used as performance measurement for the TD below the current way of working regarding the OEE will be shown.

2.3.2. Overall Equipment Effectiveness

OEE-Board

The OEE numbers are registered for every separate production line. Every hour the following information is being registered on the OEE-board: Quality, quantity and 'reasons for deviation'.

- For quality size, colour and moisture level is being written down.
- For quantity the number of products is written, and green or red marks are being registered depending on if the norm is being met (red means under norm, green is over norm).
- Reasons for deviation is filled with the causes of disturbances. (See Figure 2.5)

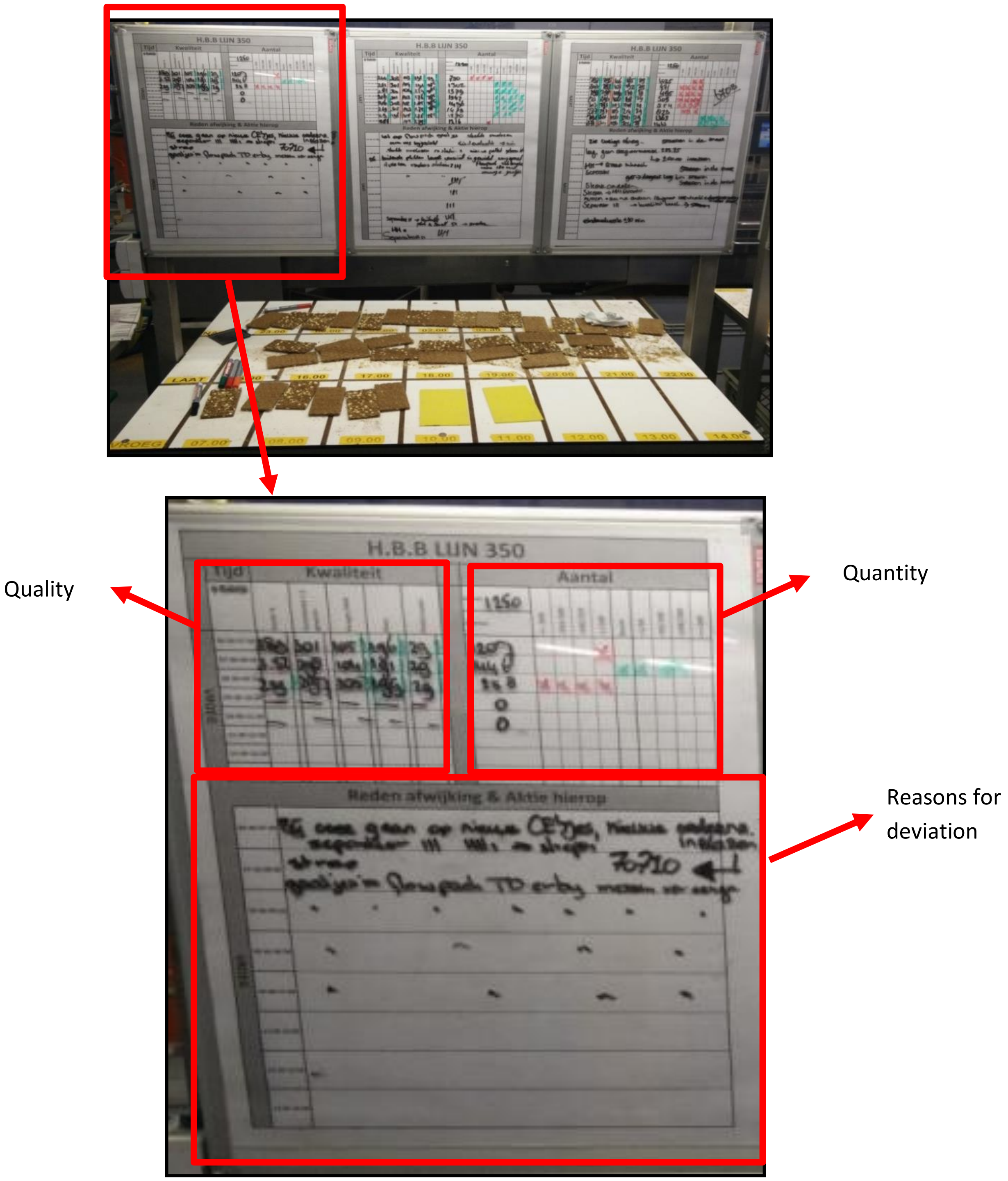


Figure 2.5: OEE-board

OEE-toolkit

At the end of every shift an operator registers the gathered data from the OEE-board into the program 'OEE-toolkit' (See Figure 2.6). Hereby the duration of production, malfunctions, startup-time, downtime and inhibitors are entered. This data is used to determine the level of availability of the line by the following formula:

$$availability = \frac{Production\ time}{Total\ time}.$$

With:

$$Total\ time = Actual\ operating\ time + Downtime + Planned\ downtime$$

Further are also the number of products produced filled in, which states the performance of the line. This performance is measured on the basis of a norm:

$$performance = \frac{Units\ produced}{Theoretical\ possible\ \#\ units\ producable}.$$

Obviously there is registration of one category of the OEE missing, namely quality. At this point it is the case that this part is not taken into account for the measurement of the OEE at Bolletje. The results of 'quality' are always set to 100%.

Figure 2.6: OEE-Toolkit

OEE-Reports

Eventually the OEE-Toolkit can be used be make reports and performance analysis. The report seen in Figure 2.7 are used in the daily morning meeting where the results of the past day are discussed. This report shows which failures occur on which machines, and what are the results for the different OEE-categories plus the eventual OEE.

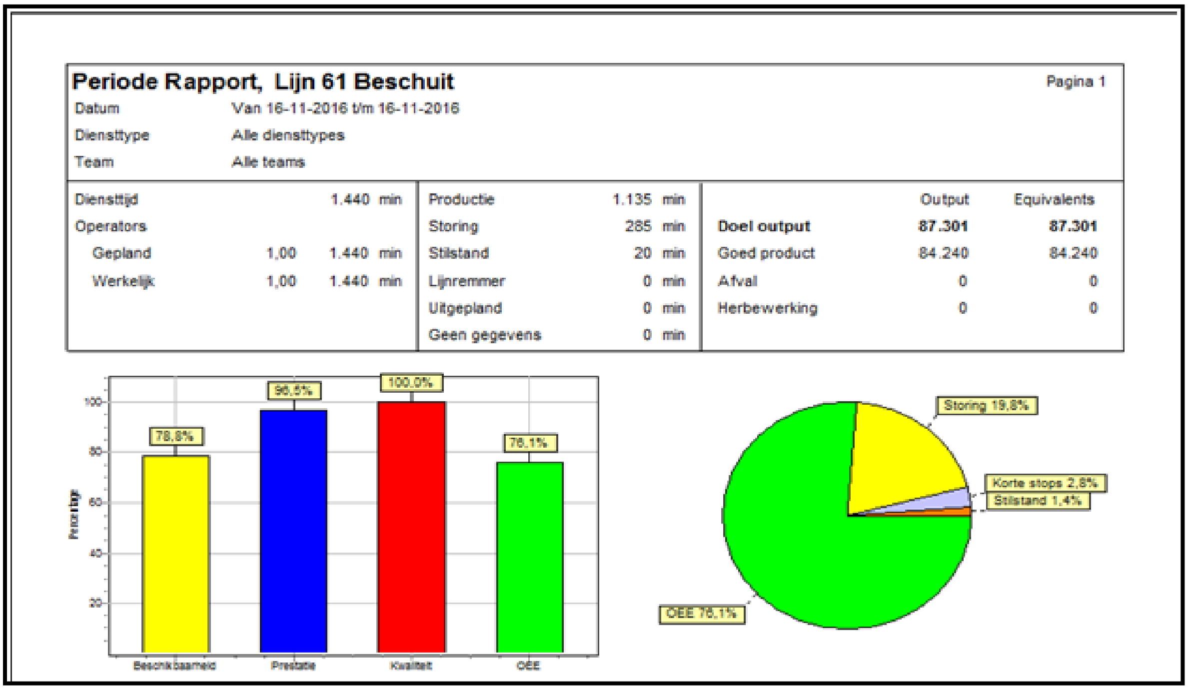


Figure 2.7: Utilization report

The report seen in Figure 2.8 is an example of an performance analysis to see what the development of the OEE figures are given a certain time frame.

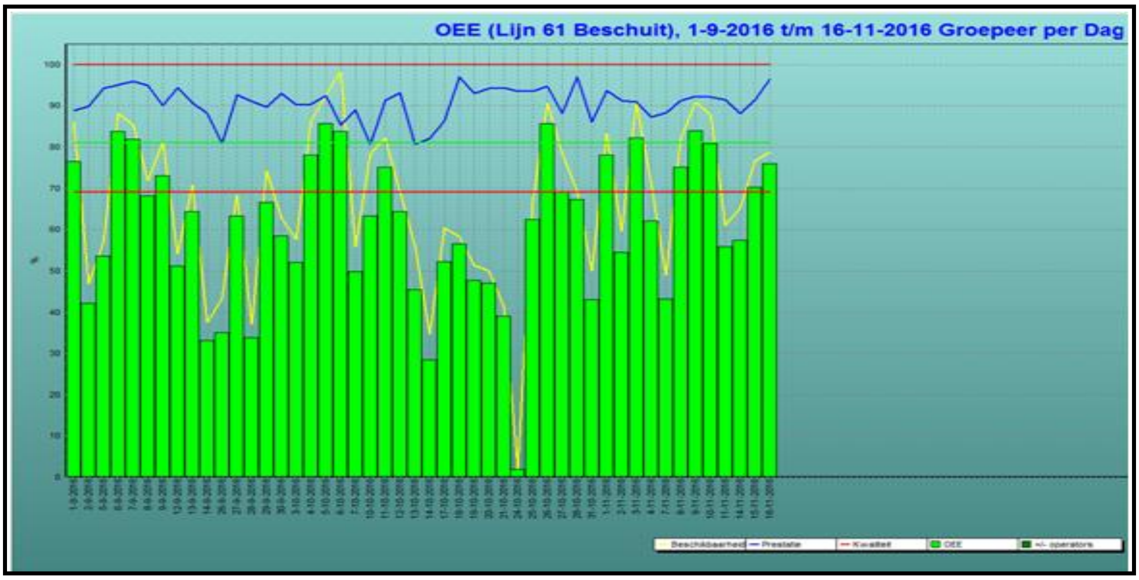


Figure 2.8: Performance Analysis

Now we know how the PD makes use of the OEE toolkit we can analyse in chapter 4.2 whether this OEE used by the PD can be of value for the performance measurement of the TD and if so, if there are changes needed.

2.4. Conclusion

From this chapter we have learned that the TD has created a new composition through a reorganization. The new organization will be focused on corrective and preventive maintenance. All other side issues as painting, lubricating and maintenance on buildings and garden are all being outsourced. Further, we have learned how the TD handles their maintenance registration in Rimses and the excel-logbook, where inefficiencies are encountered. The registration in Rimses is often incomplete and inaccurate, the registration in the logbook is very time consuming and does not create a database wherein maintenance data can be retrieved filtered with a certain filter like machine, location, mechanic or timeframe. Besides we have learned what the actual performance measurement implies for both the TD and PD. The TD is solely busy with keeping the lines 'up and running' and therewith staying within the budget. The PD keeps track of their performance with the help of an OEE-toolkit.

3. Literature

In this chapter we answer sub-question 2: *How should a Technical Department manage its maintenance activities and what is the best way to create a preventive maintenance plan according to literature?*

The starting point from this literature study is that we at least want to have information about the following cases:

- Preventive maintenance
- Performance measurement (For example: Key Performance Indicators)
- Overall Equipment Effectiveness

We start by investigating the history of Maintenance management, to have a feeling at how maintenance management has developed in the past decades. From there one we can focus more on the specific literature which can contribute to answering our sub-questions.

3.1. History of Maintenance Management

TPM originated from the fields of reliability and maintenance – a pair of closely related disciplines that have become standard engineering functions in many industries. The primary objective of these functions is to increase equipment availability and overall effectiveness. There have been four major periods in the history of maintenance management (McKone & Weiss, 1998):

1. The period before 1950 reactive maintenance had the upper hand. In this period preventing failures and defining requirements was not taken into account.
2. The second period, which saw the growth of preventive maintenance, involved an analysis of current equipment to determine the best methods to prevent failure and to reduce repair time. This period resulted from the emergence of the military equipment industry during World War II. Emphasis was placed on the economic efficiency of equipment replacements and repairs as well as on improving equipment reliability to reduce the mean time between failures. (McKone & Weiss, 1998)
3. When the economic efficiency, importance of reliability and maintenance became important the productive maintenance (the third period) became well established. Productive maintenance has three key elements: maintenance prevention, maintainability improvement and preventive maintenance.
4. The most recent period is represented by Total Productive Maintenance (TPM). TPM officially began in the 1970s in Japan. Seiichi Nakajima, vice-chairman of the Japanese Institute of Plant Engineers (JIPE), the predecessor of the Japan Institute of Plant Maintenance (JIPM), promoted TPM throughout Japan and has become known as the father of TPM. In 1971, TPM was described by JIPE as follows: 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-flow workers, to promote productive maintenance through motivation management or voluntary small-group activities (McKone & Weiss, 1998)

3.2. Tools and methods regarding Manufacturing improvement

According to Hicks & Matthews (2010) there are a wide variety of approaches and philosophies associated with the improvement of manufacturing and production systems (See Figure 3.1). In this research we are mainly interested in the maintenance part of the improvements paradigms circle (see red marking).

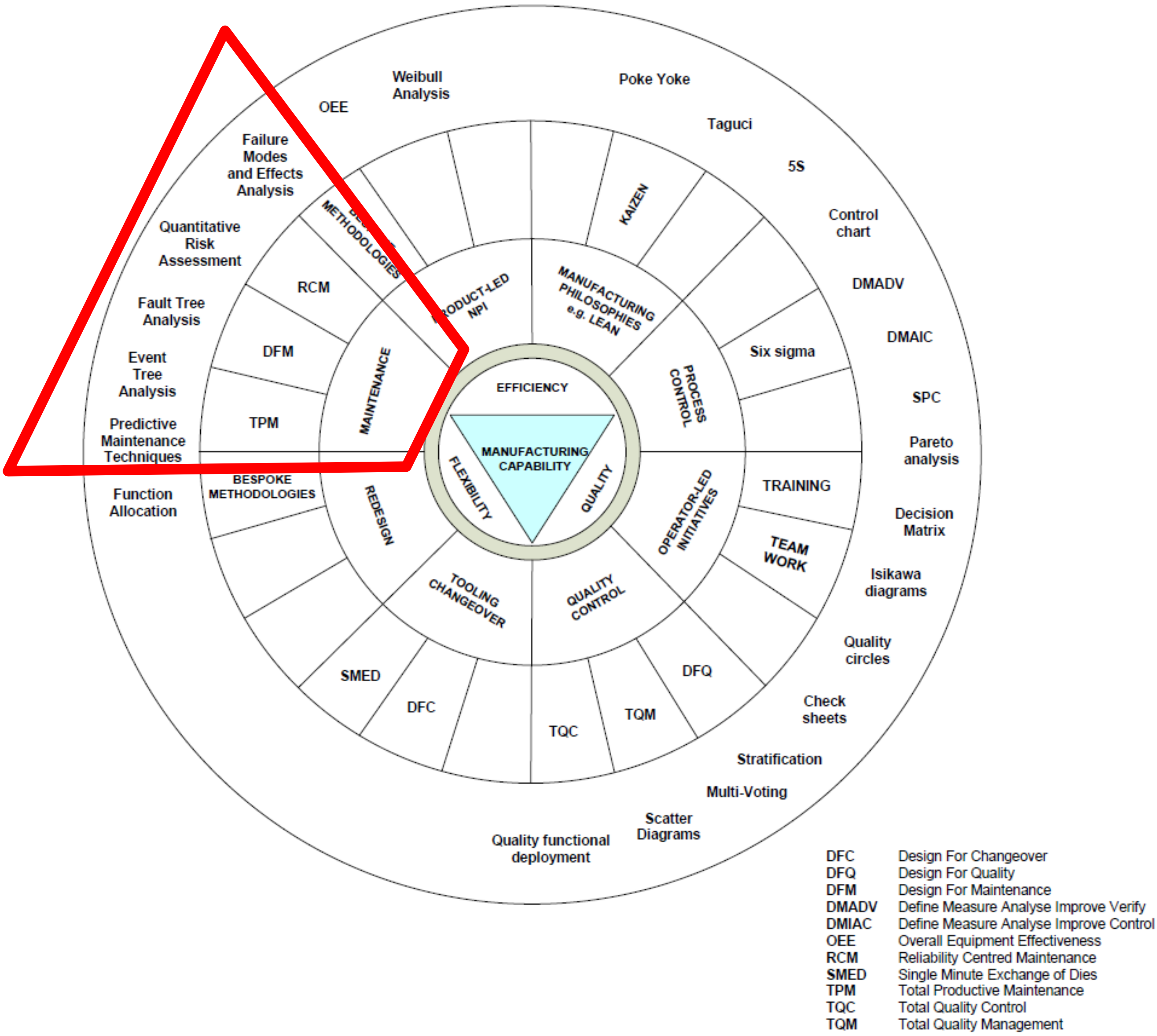


Figure 3.1: Manufacturing improvements paradigms and their corresponding tools and methods

From this maintenance part of the circle we can identify three different methods: Total Productive Maintenance (TPM), Design for Maintenance (DFM) and Reliability Centered Maintenance (RCM). We will further investigate these three methods to see which will contribute most to solving the problems Bolletje encounters at this moment.

3.2.1. Total Productive Maintenance (TPM)

The JIPM went on to identify the following five critical success factors for delivering benefits from TPM:

- Maximize equipment effectiveness;
- Develop a system of productive maintenance for the life of the equipment;
- Involve all departments that plan, design, use or maintain equipment in implementing TPM;
- Actively involve all employees from top management to shop floor workers;
- Promote TPM through motivation management: autonomous small group activities.

This focus on total involvement and motivational management brings a new perspective towards equipment management at all levels of the business. The truth uncovered through TPM is that if equipment fails to deliver its 100% potential, it is due to some physical phenomena which can be identified, brought under control, reduced and possibly even eliminated.

The simple TPM goal of ‘improving equipment effectiveness by engaging all those who impact on it in small group activities’ is supported by a powerful business- led cross-functional improvement process which is easily missed by the casual observer.

Firstly, the Key Performance Indicator (KPI) effectiveness is a measure of how well a system works compared to expectations. Classic TPM identified six effectiveness losses which account for the gap between current effectiveness levels and 100% effectiveness. The six big losses according to Chand & Shirvani (2000) are:

- Breakdowns due to equipment failures;
- Set-up and unnecessary adjustments;
- Idling and minor stops;
- Running at reduced speed;
- Start-up losses;
- Rework and scrap.

3.2.2. Design for Maintenance (DFM)

According to Das et al. (2000, p. 457) DFM was defined as “an approach for designing a product so that:

1. the design is quickly transitioned into production,
2. the product is manufactured at a minimum cost,
3. the product is manufactured with a minimum effort in terms of processing and handling requirements, and
4. the manufactured product attains its designed level of quality.”

According Stoll (1988) the DFM guidelines can be divided in three different strategies:

- Modular design
- Multi-use parts with standardization
- Ease of assembly to increase the manufacturability.

3.2.3. Reliability Centered Maintenance (RCM)

Reliability Centered Maintenance (RCM) is the process used to determine the most effective maintenance. It is defined as "series of activities generated on the base of a systematic evaluation to develop or optimize a program of maintenance. It incorporates logical decisions to find the operational and safety consequences of failures and identifies the mechanisms responsible for the above mentioned failures." (Gurumeta, 2007)

Gurumeta (2007) said the following: “In order to establish the ideal maintenance, it is essential to identify and choose the variables that determine the precise moment to carry out the tasks of maintenance. This will be done by identifying the boundaries of the system, distinguishing the different possible failures and its consequences, by a Failure Mode and Effects Analysis (FMEA).” This shows that RCM mainly consists of FMEA, as also can be seen in Figure 3.1. For that reason we will also examine the FMEA method below.

3.2.4. Failure Mode and Effects Analysis (FMEA)

In the Failure Mode and Effects Analysis (FMEA) all possible failures for a certain system are identified, but also the effects of these failures are described in terms of financial, safety and functional consequences. The analysis starts with identifying of the possible failures of components and is followed by derivation of what the consequences are. Therefore FMEA is a bottom-up method. To perform a FMEA it is recommended to create a group with people with different backgrounds. If you have different experiences from for example design, operation, maintenance and finance in the team, the chance that all possible failures are identified is bigger and that their effects are estimated with higher accuracy.

This FMEA is namely a qualitative analysis, only describing what the possible failure modes and their effects are. To create a more quantitative analysis it is necessary to add a criticality analysis. The method is then called Failure mode, Effects and Criticality Analysis (FMECA). For each failure mode the criticality is quantified by calculating the Risk Priority Number (RPN) defined as:

$$RPN_i = S_i * O_i * D_i$$

The RPN is a product of severity (S), occurrence (O) and detection (D). (Tinga, 2012)

The severity of a failure mode quantifies how big the consequences of that failure mode are. The values are typically indicated by a scale from 1 to 10 or from 1 to 5, where 1 is not severe and 5 (or 10) is catastrophic. Further, occurrence quantifies the likelihood of occurrence, e.g. ranging from highly improbable to very frequent, and the detection parameter specifies the probability that a failure is not detected when it occurs. By multiplying the three quantities, the RPN properly expresses that a failure mode is associated with a higher risk when it occurs more often (O), its consequences are more severe (S) or when the probability that the failure is not detected (D) is higher.

Although the RPN is obtained from an objective multiplication of the parameters S, O and D, the definition of the tables for these parameters and the selection of the values is still rather subjective. The obtained RPNs are not risk numbers in an absolute sense, since they depend on the chosen scales. “This means that the boundary between acceptable and unacceptable risks should be determined for each analysis separately. Finally, the three quantities S, O and D quantify rather different aspects of risk. It should be realized that an increase in occurrence (O) not always represents the same increase in risk as an equally large increase in severity (S). Therefore, the obtained RPN values should be interpreted with care.” (Tinga, 2012) The FMECA is a tool to identify the possible failures for a certain system and what their effects are, but does not contain a decision tool to decide which action should be taken to reduce these risks. Obviously this is desirable, so it is decided that a tool should be selected which helps with the determination of the right kind maintenance policy. This will be discussed in the following section 3.2.5

3.2.5. Maintenance policy decision method

Waeyenbergh & Pintelon (2002) developed a framework for maintenance concept development in which also a decision tree is developed to select the correct maintenance policy (see Figure 3.2).

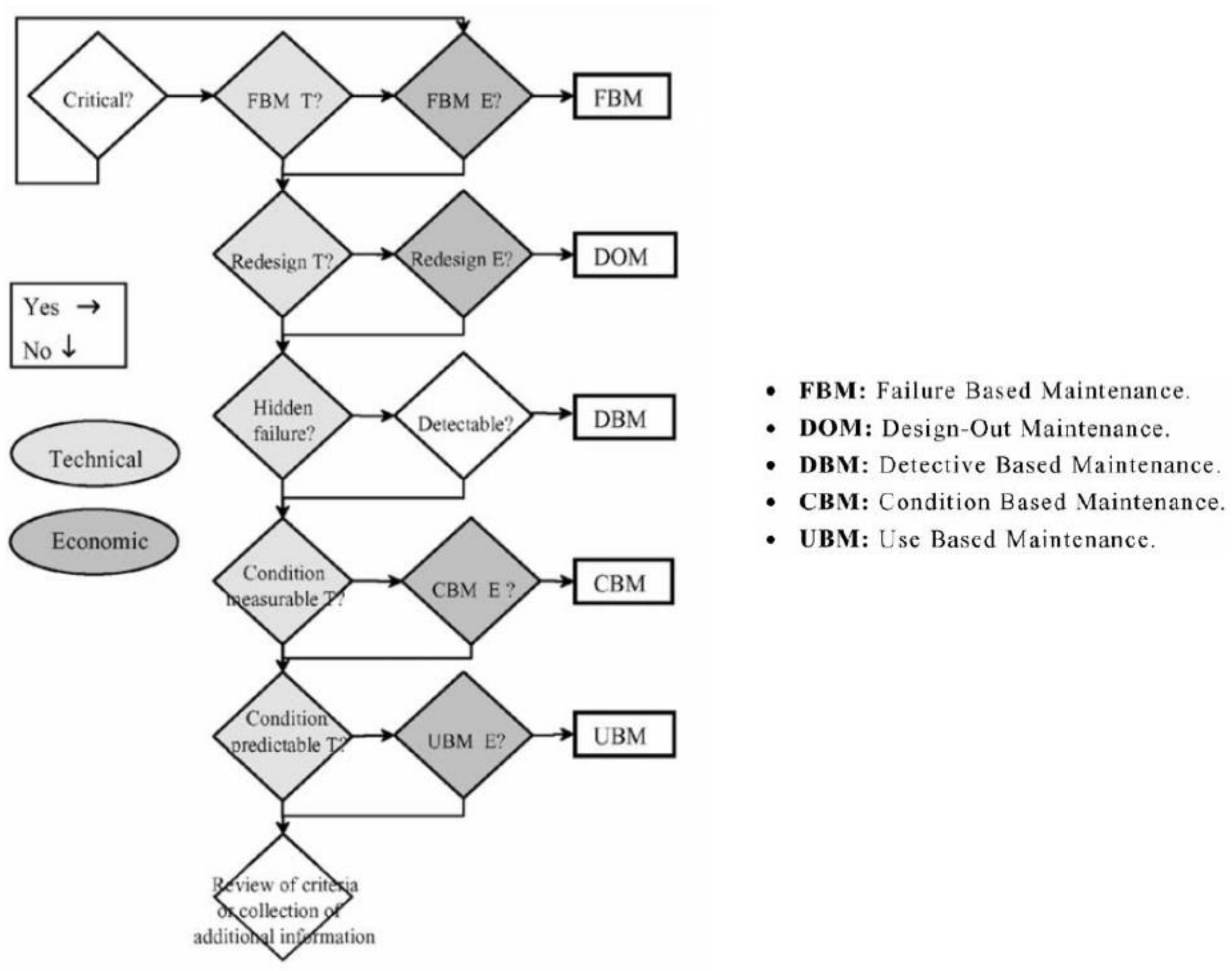


Figure 3.2: Maintenance decision policy tree (Waeyenbergh & Pintelon, 2002)

The tree consists of 11 questions (technical as well as economic) that can be answered with yes or no. Dependent on these answers one of the maintenance policies shown in Table 3.1 will be chosen for that particular part.

Type of Maintenance policy	Description
Failure Based Maintenance (FBM)	Simply ‘run to failure’
Design-out Maintenance (DOM)	Improve design to ease or eliminate maintenance
Detective based Maintenance (DBM)	Detect with human senses if part is reaching final stage of failure
Condition Based Maintenance (CBM)	Measure/monitor condition of part
Use Based maintenance (UBM)	Maintenance carried out after a specified amount of time

Table 3.1: Maintenance Policies

3.2.6. Conclusion regarding Tools and Methods

TPM could be a very useful tool to improve the performance of the Technical Department. It is also recommended that in the future this method should be applied within the organization of Bolletje. For this research it is decided not to implement this method yet. The impact for the complete organization of Bolletje would namely be huge. And as said in 3.2.1: “This focus on total involvement and motivational management brings a new perspective towards equipment management at all levels of the business”. This means that this implementation of TPM requires a lot of time of the complete organization (Not only the TD, but also the PD and the complete Bolletje management). At this moment the organization is not capable to meet this requirement, because a lot of the available time is used to solve the ‘low hanging fruit’ of their own organization.

The DFM is mainly oriented in the design-phase of a production line. Because my research does not have any interface with the design phase of production lines. Note that at this moment there are no designs made for new production lines or whatsoever. Moreover it would also not be possible to redesign the current machines, because this would ask too much production time availability, which simply is not available. For this method the same applies as for TPM; in the future it might be a very useful tool to help improve the design of possible new production lines to ease the maintenance, but at this moment DFM is not what the organization is asking for right now.

RCM, on the other hand, is exactly what the TD is asking for at this moment. As said in 3.2.3 “RCM is defined as a series of activities generated on the base of a systematic evaluation to develop or optimize a program of maintenance”. This fits perfectly with the question of the TD how to create a preventive maintenance plan. As also could be read in the 3.2.3 RCM mainly consists of the execution of the FMEA. So with the answering of sub-question 6: *What steps should the TD follow towards a successful preventive maintenance plan?* , we will follow the FMEA method and the maintenance policy decision method to ensure the proper preventive maintenance plan is generated.

3.3. Key Performance Indicator (KPI)

As said in section 3.2.1 a measure of how well a system works compared to expectations can be achieved with the help of KPIs. To define the KPIs for the TD in such way it creates insight in the performance, it is necessary to review relevant literature regarding KPIs. This literature will give right understanding of KPIs and what requirements they must meet.

3.3.1. Definition of KPI

Performance measurement is a fundamental principle of management. It is important because it identifies current performance gaps between current and desired performance and provides indication of progress towards closing the gaps. Carefully selected KPIs identify precisely where to take action to improve performance (Weber & Thomas, 2005). KPIs represent a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization (Parmenter, 2007). There is a difference between 'leading performance indicators and lagging performance indicators. (See Figure 3.3). Leading indicators monitor if the tasks are being performed that will 'lead' to results. On the other hand, lagging indicators monitor whether the results or outcomes that have been achieved. Both leading and lagging indicators are therefore important for managing the performance of the maintenance function. Moreover, the leading indicators are even more important than lagging indicators because they have the potential to avoid unfavorable situations from occurring (Muchiri, 2010).
Many organizations that have operated with KPIs have found the KPIs made little or no difference to performance. Establishing a sound environment in which KPIs can operate and develop is crucial. Once the organization understands the process involved and appreciates the purpose of introducing KPIs, the building phase can begin (Parmenter, 2007).

In 2007, Parmenter defined seven KPI characteristics:

1. Nonfinancial measures (not expressed in dollars, yen, pounds, euros, etc.)
2. Measured frequently (e.g., daily or 24/7)
3. Acted on by the CEO and senior management team
4. Understanding of the measure and the corrective action required by all staff
5. Ties responsibility to the individual or team
6. Significant impact (e.g., affects most of the core critical success factors [CSFs] and more than one Balanced Scorecard perspective)
7. Positive impact (e.g., affects all other performance measures in a positive way)

In the following, section we shall zoom in on how to make KPIs useful for a maintenance environment.

3.3.2. KPI & Maintenance

Muchiri (2010) developed a maintenance performance framework as shown in Figure 3.3, which outlines the key elements that are important in maintenance management.

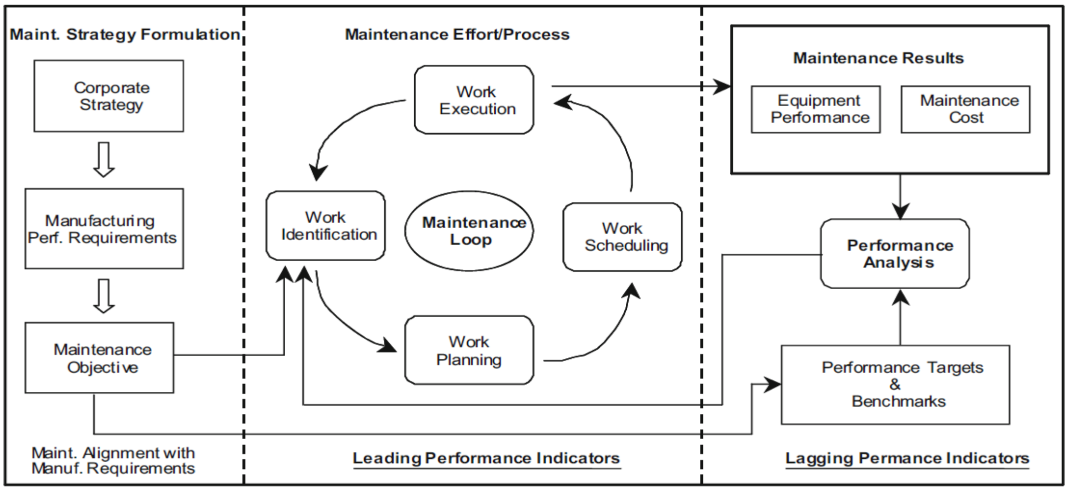


Figure 3.3: Maintenance performance framework (Muchiri, 2010)

The elements ensure the right work is identified (based on the set objectives) and effectively executed for guaranteed results that are in line with the manufacturing performance requirements. For each element, the main challenge is to identify the performance indicators that will tell whether the element is managed well. This raises the question of what makes a good performance indicator.

According to Muchiri (2010) good indicators should:

- support monitoring and control of performance,
- help identification of performance gaps,
- support learning and continuous improvement,
- support maintenance actions towards attainment of objectives
- and provide focus of maintenance resources to areas that impact manufacturing performance.

3.4. Overall Equipment Effectiveness (OEE)

OEE measurement tool was developed from the TPM concept launched by (Nakajima, 1988). OEE is defined as a measure of total equipment performance. It is a three-part analysis tool for equipment performance based on its availability, performance, and the quality rate of the output. It is used to identify for an equipment the related losses for the purpose of improving total asset performance and reliability. The OEE tool is designed to identify losses that reduce the equipment effectiveness. These losses are activities that absorb resources but create no value.

The six big losses (see section 3.4) are measured by OEE, which is a function of availability (A), performance (P) and Quality rate (Q). In Figure 3.4 the OEE calculation is shown.

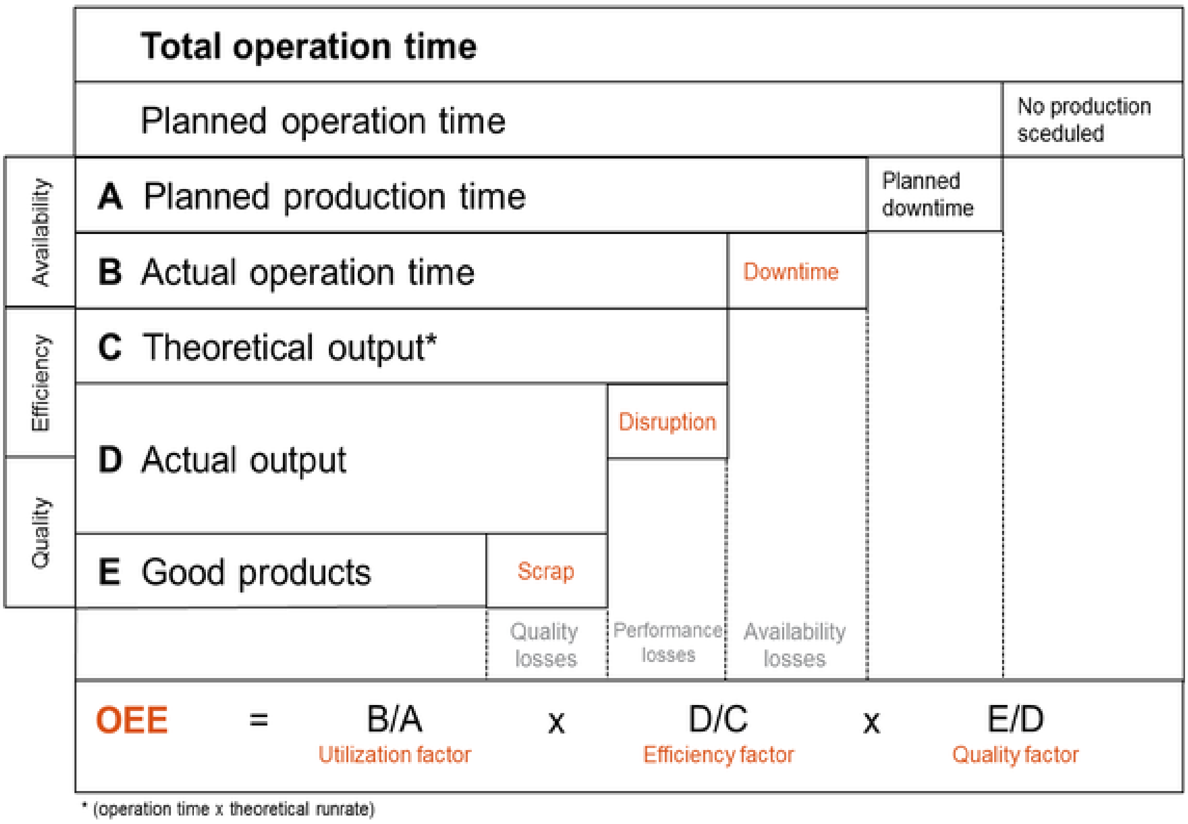


Figure 3.4: OEE Calculation

The OEE measurement tool has its strength in the way it integrates different important aspects of manufacturing into a single measurement tool. (A Pintelon & Muchiri, 2010)

3.5. Conclusion

We answer sub-question 2: "*How should a Technical Department manage its maintenance activities and what is the best way to create a preventive maintenance plan according to literature?*" as follows:

The most suitable solution for creating a preventive plan in the situation of Bolletje is making use of 'FMECA' and 'Maintenance policy decision method', to first determine the risks priority numbers for all critical components and thereafter create a preventive plan.

Further we have seen which KPI-characteristics there are and to which requirements a good KPI should meet, for example that it should support monitoring, help identification of performance gaps and support maintenance action. This will help us in section 4.1 where KPIs will be determined for the TD.

From section 3.4 we have learned how the original calculation of the OEE was conceived. This information will help us in chapter 4.2, where we will research whether the OEE is a reliable source for the measurement of the KPIs which are determined in section 4.1.

4. Performance measurement

In this chapter, we will answer Sub-question 3: "What Key Performance Indicators give a representative review of the performance of the Technical Department?" and sub-question 4: *To what extent are the OEE statistics used by the Production Department a reliable source for measurement of these KPI's?*

4.1. Key performance indicators

On the basis of the literature regarding KPIs given in section 3.3 a meeting with the TD manager was held. In the literature discussed in section 3.3.2 it was said that for every element in the Maintenance Performance Framework a KPI should be chosen. According to Muchiri (2010) this would mean at least 6 to a maximum of 31 performance indicators.

The goal of this meeting was to have at least three defined KPIs at the end of the meeting. The choice for three KPIs was made, because it is the first time KPIs are being used in the TD organization. Therefore, we chose for a cautious approach with a limited number of KPIs to ensure a good absorption in the organization with a possibility for extension in the future.

The three KPIs forthcoming from this meeting where:

- Production line availability
- Preventive maintenance time / Corrective maintenance time
- Mean Time To Repair (MTTR)

This is presented with a dashboard, where the different production lines can be selected on the hand of selection tool in the form of a slicer. With these slicers also the timeframe can be selected, but normally a time frame of a week should be a correct performance measurement of the TD for all three KPIs, where you could see the KPIs for every production line, but also in total. In the following three sections (4.1.1, 4.1.2 and 4.1.3) the choice for these three KPIs are further discussed.

4.1.1. Production line availability

This first KPI was based on the goal of the TD also described in section 1.3, namely:

The goal of the TD is to let all production lines produce as good as possible by conducting corrective and preventive maintenance in an optimal way.

The first part *"let all production lines produce as good as possible"* should be used as KPI, to measure the extent to which this TD goal is met. The most obvious thing to do first is to look at the OEE figures. The OEE is a combination of measurements of availability, performance and quality. It is a possibility to choose for the total OEE figures, because this translates the overall performance of the production lines. But because the TD does not have influence on the performance and is namely responsible for the availability of the production lines it is chosen to only use 'availability' for this first KPI.

Availability will be defined as in Figure 3.4; so $\frac{Actual\ Operating\ Time}{Planned\ Production\ Time}$

This choice is made because from section 3.3, it is known that a condition for a good KPI is that it should 'drive action' for the ones involved. This driving action is only guaranteed when you have full responsibility for the KPI and therefore only production line availability is used for this KPI.

4.1.2. Preventive / Corrective maintenance ratio

The second KPI is also based on the goal of the TD, but is distracted from the last part: *"by conducting corrective and preventive maintenance in an optimal way".* From section 1.3.1 we know that a lack of preventive maintenance is a problem which is limiting the TD performance. To reach the goal of the TD it is thereby necessary to improve the preventive / corrective maintenance ratio. With this ratio is meant the man hours that is invested in preventive maintenance versus the man hours that is invested in corrective maintenance. The goal is to increase the ratio number by investing more time in preventive maintenance, which ensures that less corrective maintenance is needed to keep the full machinery of Bolletje up and running.

4.1.3. Mean Time to Repair (MTTR)

From the KPI-meeting with the TD Manager arose the third KPI: MTTR. It was said that the aim regarding failures is to resolve them as quick as possible. The best way to measure this statement is on the basis of the average time duration of a failure. So the time from the moment when a failure mechanic gets called until the moment that the failure is released and approved by the PD.

4.1.4. KPI Conclusion

The answer to sub-question 3: "What Key Performance Indicators give a representative review of the performance of the Technical Department?" is:

- Production line availability
- Preventive maintenance time / Corrective maintenance time
- Mean Time To Repair (MTTR)

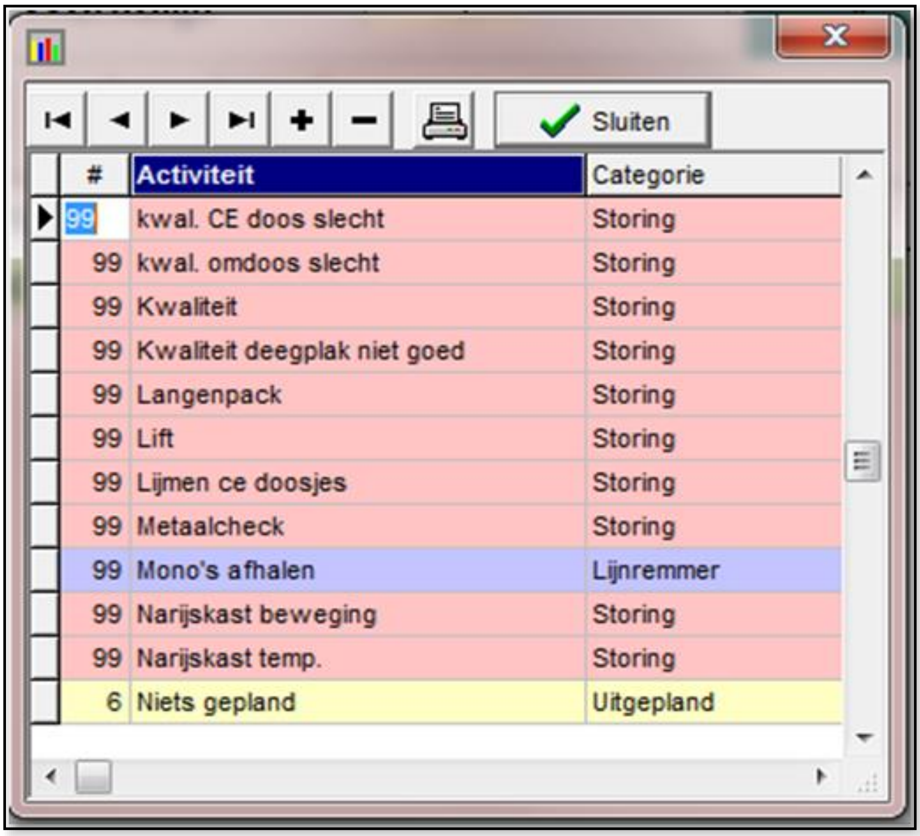
With the measurement of the three KPIs mentioned above a start can be made towards performance measurement of the TD. We recommend to monitor and show the KPIs in a place where each employee of the TD is triggered to increase the KPI results with the help of an interactive dashboard. You could think of a display in Excel with the help of pivot tables and slicers. Then it is also necessary to create some sort of integration between the OEE-toolkit and Excel. When excel is not sufficient it is advised to research additional possibilities of dashboard displays in the form of professional KPI dashboard programs. After a period of three months of usage of the mentioned three KPIs a session should be planned to determine if this number of KPIs is of sufficient added value, and therewith if additional KPIs need to be defined.

4.2. OEE

4.2.1. Quality registration

As said in section 2.3, Bolletje ignores the ‘quality’ category in the OEE-figures, simply by letting the quality-category set to 100%. In reality, this is not really the case, because loss due to quality is being registered, but not on the way it originally was meant.

As can be seen in Figure 4.1 ‘Quality’ (Dutch: Kwaliteit) in the master data of the OEE-toolkit are registered as malfunction (Dutch: Storing). So in this way the ‘quality’ part is not registered under the ‘quality’ part in the OEE, but is registered under ‘availability’.



#	Activiteit	Categorie
99	kwal. CE doos slecht	Storing
99	kwal. omdoos slecht	Storing
99	Kwaliteit	Storing
99	Kwaliteit deegplak niet goed	Storing
99	Langenpack	Storing
99	Lift	Storing
99	Lijmen ce doosjes	Storing
99	Metaalcheck	Storing
99	Mono's afhalen	Lijnremmer
99	Narijskast beweging	Storing
99	Narijskast temp.	Storing
6	Niets gepland	Uitgepland

Figure 4.1: Master data activities

Example

To exemplify the fact described above an example of this case will be shown below:

For the production of Knäckebröd at 'line 350' the operators are supposed to put different ingredients together in the molder. Normally throughout the shifts this goes without errors. But sometimes when there is a shift change, the operators are transferring production information, chatting here and there and are not always fully concentrated on the composition of the ingredients with the possibility that one of the ingredients is forgotten.

Result: one batch with wrong recipe (which is 20 minutes of continuous knäckebröd production) has a dough which reacts differently throughout the production line. For example it does not get the right height, color, weight or something similar. When half an hour later the dough reaches the packing station, and the height is wrong, the packaging operators call the dough preparation operators to inform that the height is too low, and that the sheet of dough should be increased in height. What they don't know is the fact that this loss of height was because an ingredient was forgotten. The dough preparation operators change the machines to increase the height, with as a result that half an hour later the dough (now with the right ingredients) is much too high.

Due to this forgetting of the ingredient a production loss of at least one hour is caused, because the knäckebröd did not meet the height standard during this hour. This is registered as 'quality sheet of dough not good' (Dutch: 'Kwaliteit deegplak niet goed', see Figure 4.1). This is thus registered as category malfunction (Dutch: 'Storing', see Figure 4.1), but in fact this should be registered as loss due quality, because this is not a malfunction which caused the line to be not available, but simply bad quality product is produced on an available production line.

What should be done in the situation described in the example above, is the following:
We assume that this happened in a shift of eight hours, where the molder had one hour of failure and one hour of production loss (the produced knäckebröd did not fit into the packaging) was due to the forgetting of one ingredient. So six hours of good production was achieved. A total of 11.000 good packaged products was produced, while a theoretical of 14.000 products was possible in the 7 hours. Note that the theoretical number of products producible is dependent on the number of hours available.
In the old situation would it be registered as follows:

$$Availability = \frac{(8-2) = 6\ hours}{8\ hours} = 75\%$$

$$Performance = \frac{11{,}000\ (good\ units)}{12{,}000\ (2000\ in\ every\ hour)} = \ 91.67\%$$

$$Quality = 100\%\ (always\ set\ to\ 100\%)$$

$$OEE = 75\%\ x\ 91.67\%\ x\ 100\% = 68.75\%$$

Bolletje

In the new situation it would be registered as follows:

$$Availability = \frac{(8-1) = 7\ hours}{8\ hours} = 87.5\%$$

$$Performance = \frac{12{,}833\ units\ produced\ (including\ bad\ quality\ products)}{14{,}000\ possible\ units\ (2000\ in\ every\ hour)} = \ 91.67\%$$

$$Quality = \frac{\frac{6}{7} * 12{,}833 = 11{,}000\ good\ units\ produced}{12{,}833\ units\ produced} = 85.7\%$$

$$OEE = 87.5\%\ x\ 91.67\%\ x\ 85.7\% = 68.75\%$$

For the final OEE-figure it makes no difference where quality is registered. But registering the quality category by following the literature discussed in section 3.4, does contribute to the right understanding regarding the production line functioning. Because it visualizes the difference between availability and quality.

KPI Measurement

Besides, this change will also contribute to the KPI measurement discussed in section 4.1.1: Production line availability. If the quality would still be registered under the availability-category, this would be not a representative number for the availability KPI. But if registration of quality would be registered in the way proposed earlier the availability-category can be directly used as measurement of this KPI.

4.2.2. Conclusion OEE

In section 4.2 we answered sub-question 4: *"To what extent are the OEE statistics used by the Production Department a reliable source for measurement of these KPI's?"*

We can answer this question positively for the measurement of the KPI 'Production line availability' if the category 'quality' will be taken into account within the OEE-registration as discussed in 4.2.1. In that case the resulting percentage in the category 'availability' can be directly used as result for the 'Production line availability'-KPI. The OEE statistics cannot be used for the other two KPIs, simply because within the OEE no information is stored regarding preventive / corrective maintenance and because the malfunction registration does not accurately register the mean time to repair. The information for these two KPIs can be directly extracted from the Rimses database.

5. How to register Maintenance Data

In this chapter, we answer sub-question 5: *How should the registration of maintenance activities be organized so that it is value-added for making a preventive maintenance plan?*

As said in section 3.2.6 the FMECA method will be used to analyze the risks of failure for the equipment. This risk determination will be used as input for decisions regarding the preventive maintenance plan. That's why we will answer the sub-question stated above in such way it the maintenance data contributes as good as possible to the FMECA method.

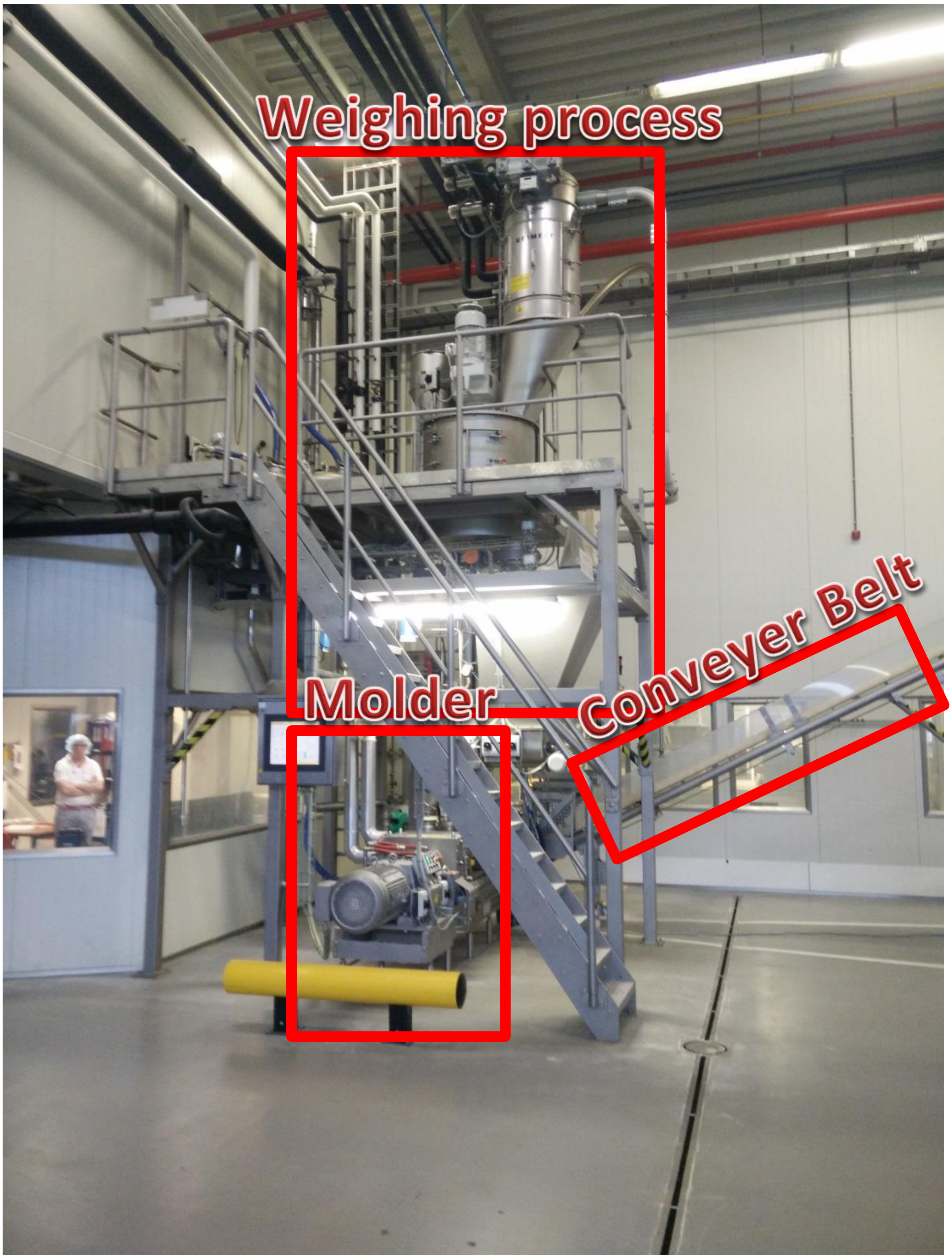


Figure 5.1: The dough preparation installation of 'Lijn 61', which gathers the right ingredients in the weighing process, kneads it in the molder and deposes it on the conveyer belt.

To create better understanding of the discussed issues a 'running example' will be used. This running example is the process dough preparation of the production line 'lijn 61'. This production line is the biggest 'beschuit'-production line of Bolletje. Within the process 'dough preparation' the different ingredients are gathered from the right silos. Hereafter the ingredients are weighed and subsequently deposited into the molder. The molder will continuously knead the different ingredients into a dough which comes out of the other side of the molder and automatically falls on a conveyer belt. The depositing of the dough onto the conveyer belt is also the end line where the process 'dough preparation' will stop. From here one the next process starts, namely 'dough transportation' (see conveyer belt in Figure 5.1).

5.1. Overview Machine Structure

As said in section 2.2.1 the current Overview Machine Structure is incomplete and not logical. To tackle both problems the structure should be divided into more sub-processes and should be made complete with all parts that are present in that sub-process. Now raises the question how far you should go, for example you could say that a pump also has very small parts like gasket and should you register this gasket of you will never change it? The rule of thumb we advise to keep in mind is that if you disassemble the machine, and a certain part comes off as a whole and you change it as a whole, that this part is the last level of detail which you will register. So if you change the pump as a whole the last level is the pump, but if you change the gasket of that particular pump you will also need to register the gasket in your machine structure.

Further, you want the machine structure arranged in such way it is suitable for machine-inspections. For example, in the FMECA (see section 6.2) you determined the following possible failure: The filters of a certain installation are blocked. When these filters are blocked, the consequence will be that the installation fails, which causes operational delay for the entire production line. An action to prevent this from happening is monthly inspection of the filters. To easily create an inspection list for these filters in Rimses it is very convenient to group all filters under one group.

To show how this should be executed the 'running example' process dough preparation is already elaborated in Figure 5.2:

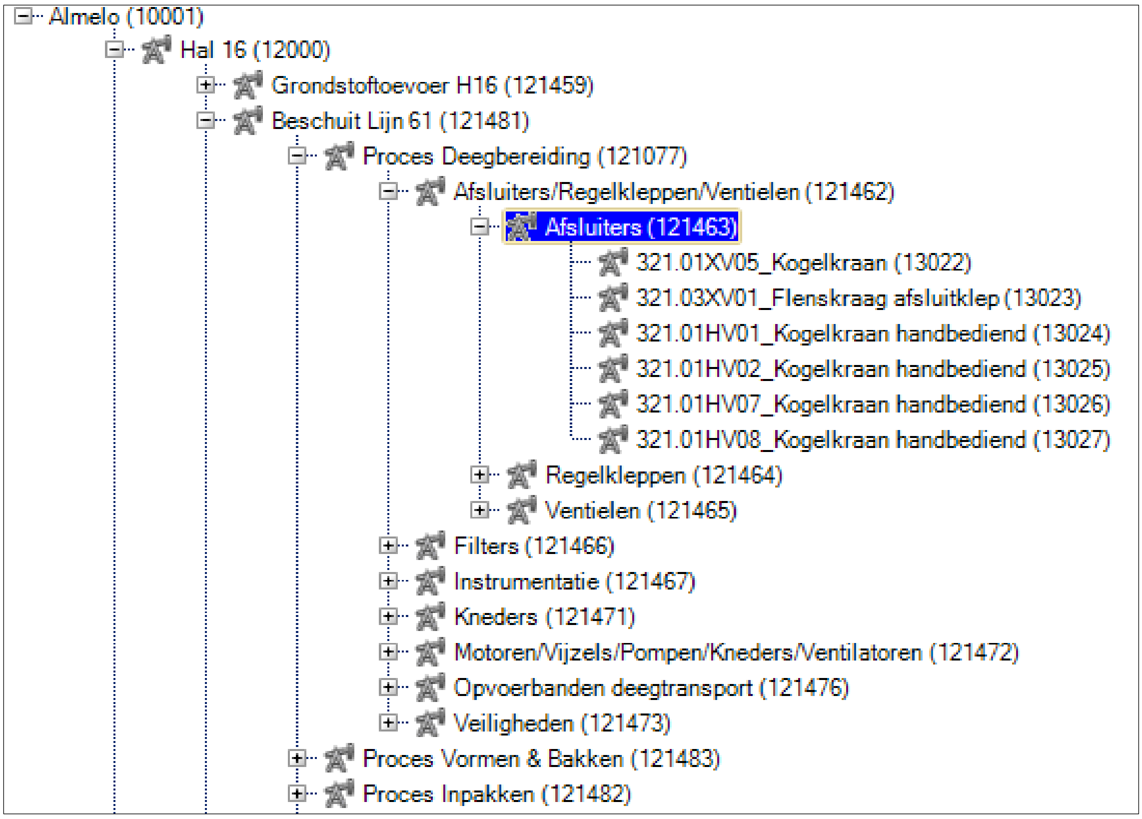


Figure 5.2: The new Machine Structure with

Here you can see that every valve (Afsluiter) is registered, which demonstrates that the structure is complete at the right level of detail. Namely if a valve breaks down, the complete valve will be replaced. (Notice that this completeness is also the case for the other components, only intentional left folded to show the groupings overview). Further it is shown there are groupings made like filters, valves and control valves to meet the convenience of creating organized inspection lists.

5.2. Work Order Registration

Obviously it is important to register maintenance data accurately to keep good insight in the complex maintenance process where you have to organize: planning of mechanics, ordering of parts, outsourcing to external parties, prioritizing disruptions and transferring of knowledge between different shifts. This data also needs to give the proper display of cost allocation, i.e., what are the costs and benefits of certain parts or machines of the machinery. Further you want to accurately analyze what the chances of failure are based on the failures that has already occurred. This is namely one of the most important inputs for the FMEA. This maintenance history can also be used to define possible failure in the first phase of the FMEA.

It will be not taken into account in this research, but in a further stage it may also be important to analyze whether a part should be put on stock or not. This will be based on information like:

- What is the criticality of a part?
- Mean time between failure (how often is a part needed)
- Replenishment Lead time
- Mean time to repair (If it fails, how long does it take to repair it)
- Costs (inventory costs vs loss of production+ man hours costs + material costs)

Summarized it can be said that registration of maintenance activities in the form of WOs is the most important source of input for the decisions the TD organization makes.

As showed in section 2.2.1 the work order registration at this moment seems very devious, inaccurate and time consuming. The solution to this problem can be found closer than you expect. Rimses is namely in co-operation with a mobile software developer to develop a mobile app to register the prios 1 and 3 directly with the help of a smartphone (see Figure 5.3).

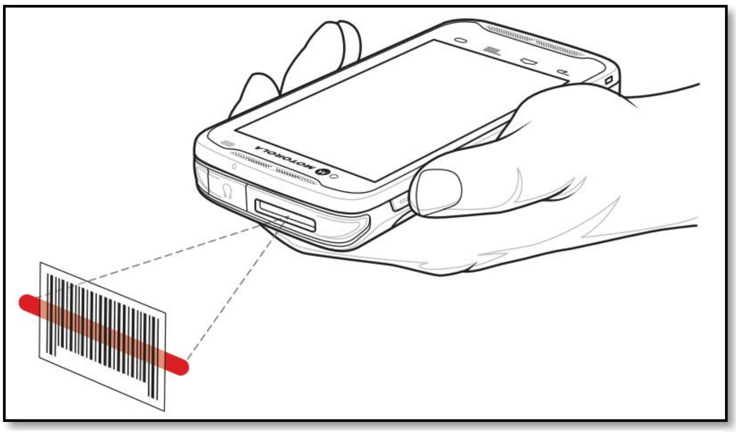


Figure 5.3: Smartphone with 2D-scanner used by the TD

Recall that Prio 2 is present within the program, but this category gradually disappeared from the work environment. Therefore we will discuss what handling prio 1- and prio 3-WOs with the help of the app means.

5.2.1. Prios 1

Registration of the prios 1 in the app is handled in the following manner:

1. An operator calls the TD for a malfunction, and there stops the responsibilities for him/her, in contrast with the old situation, where he had to make a WO and assign it to the right machine.

Figure 5.4: Machine Barcode used to identify every machine in the factory

- The mechanic starts a WO simply by clicking ‘Start prio 1’ in the app. At this moment the time registration starts running.
- When the mechanic arrives at the machine he can scan a barcode attached to the machine (see Figure 5.4) with the smartphone/scanner.
- This is all he has to do, because the app will attach the WO to the right machine in the machine structure at the hand of the barcode.
- When it is necessary to assign used parts to a WO this can simply be performed by scanning the barcode of that part which is attached to the shelf or storage rack where that part lies.

- When the mechanic is finished, he can fill in the WO at the location he is at that moment. There is no more need to return to the workshop to fill in the WO in a computer. With filling the following issues are mentioned:
  - Work Description
  - Type of work
  - Symptom
  - Cause
  - Action
  - Detailed explanation of executed work.
- The performed work can be signed by the operator on the touchscreen of the smartphone, wherewith we comply with audit requirements.
- The time registration stops at this moment and the work hours are registered with a significance of one minute into the WO.

With the use of this App the devious way of working with Prios 1 is made more efficient. There is a big time saving, because the following steps of the old situation can be skipped:

- The operator does not have to create a WO in E-Rimses
- The operator does not have to search for the right machine in E-Rimses
- The operator does not have to print a WO on an a4-paper.
- The mechanic does not have to walk back to the workshop to register performed work
- The mechanic does not have to search the WO in Rimses to register his performed work
- The mechanic does not have to search the used parts in Rimses
- The mechanic does not have to register the worked hours
- The TD team leader does not need to scan and save all printed A4 papers to fulfill audit requirements

All these steps together will save 20 minutes for a mechanic per shift. This comes down to a total of 16,7 hours per week for all ten mechanics, which are using the app (see section 5.2.4).

5.2.2. Prios 3

For the Prios 3 it almost works the same, the difference is only that the mechanics do not start a prio 1, but the prios 3 assigned to him are shown as a to-do-list in the app. All information that a mechanic needs to know is already filled in by the planner. The mechanic simply has to click a WO that he wants to perform and again the time registration starts. Obviously the planner already indicated which machine needs to be repaired, so the scanning of the right machine is here not necessary, but for the registration of used parts the same applies as for the prios 1. Also the filling in (or complementing) of the WO can be registered right on the place of repair. Same applies for the acceptation and signing of the performed work by the operator which is owner of that machinery.

5.2.3. Implementation phase

During this research the implementation phase of the app-usage is already started. Rimses has partnered with Aidoo Mobile to develop the app. To remove all de startup errors regarding the usage of the app Rimses organized a pilot for potential users. Eventually Bolletje was the only company participating in this pilot and therefore was the only one responsible for supply of imperfections. In cooperation with one of the mechanics and the TD team leader the initial difficulties were filtered out. Every found defect or imperfection is communicated towards Rimses, so that they can fix the encountered problems.

Examples of found errors are:

- Change designation of fields and menu items for better understanding
- Make sure that right fields in main program of Rimses are filled with right fields of the app
- Make sure that app fields have same character limitation as in the main program.
- Make the fields that are obligated in main program of Rimses also obligated in the app
- All kinds of communication errors between Rimses database and Mobile database (In fact we run up against error messages due to testing of the app and send these through).
- When a field entry ended with a 'space', an error would occur, Rimses changed their program logic, so this will not create an error.
- Switching between mechanics (I.e. logout of the one mechanic and login of the following mechanic) takes a lot of time due to the fact that the full database needs to be downloaded with a login, Rimses is trying to change the login design.
- In the main program it is possible to create continuation-WO, in the app this is not possible, and Rimses is investigating if this would also be possible within the app.
- In the app it is possible to pause an activity. When this is done, the eventual start and end time is not registered correctly, Rimses is trying to register the initial start time as start time, and the time the WO is finished as end time.

Due to the solutions for all these encountered problems the TD now has a stable process regarding the registration of their prios 1 and 3 with help of the app. The first of January the TD completely switched to the app-registration and all mechanics are very pleased with the ease of use and all the time that is saved thanks to working with the app.

5.2.4. Financial benefits

The costs per used account per month is €50,-. The maximum amount of accounts that are used at the same time will be six. So the additional costs for the app will be €300,- per month. The investment that has to be done for the 10 PDAs with BAR-code scanners is a total of €8,000. The expected life time of the PDAs is at least 4 years.

Time saving

One first advantage of the app usage is the time saving of registration of maintenance activities. It is proven that a time saving of at least 12 minutes per mechanic per shift is achieved. Think hereby of elimination of the actions described in Table 5.1.

Action (old situation)	Action (app situation)	Time saving (minutes)
Starting up computer and logging into Rimses	Start app right away	2
Redundant activity registration in Rimses and Excel-logbook	In the app registration is needed once and also automatically shown in the logbook, as discussed in section 5.3	6
Searching objects in the machine structure	The app scans the machine, so searching is unnecessary	3
Searching used parts in Rimses	The app scans the parts, so searching is unnecessary	3
Operator needs to create a WO in E-Rimses, print WO and bring it to the mechanic	WO is created in the app	5
All printed WO pages needs to be scanned and saved	Signature is saved in app and automatically put in Rimses database	1
	Total:	**20**

Table 5.1: Financial benefits of time saving regarding registration of WOs

During the 24 hours of one day a total of ten mechanics are working. So per day 200 minutes is saved. This is 16.7 hours per week and (16.7*52)/12 = 72.2 hours per month. The hourly wage TD calculates for a mechanic is €40,-. This comes down to a total of €2,888 , which is saved due to the use of the mobile app. Subtract the costs of €300 for the app-licenses and you will have a net profit of €2,588 per month**.** Note that this amount has not been saved in the way that you don't spend it, but it is saved in the way that you will have more available time where the mechanics can carry out value added operations. Further note that payback period for the PDA-investment is just above three months: € 8,000/ €2,588 = 3.09 months.

Better performance (Inexpressible in figures, but indirect will give financial benefits)

- More accurate registration (descriptions, man hours, duration) on the right machine and right level of detail. This will give more accurate information about failure behavior and total maintenance costs of your machinery
- More accurate registration of used parts. This will contribute to better inventory management with less change on 'out-of-stock' situations, with possible production loss and rush order costs.

5.3. Logbook

In fact Rimses is highly appropriate for an extensive registration of performed work (See Figure 5.5) There is namely a tab present within the creation of a new WO (this tab is also filled when a WO is registered in the app) where you accurately can register the performed work. This is never used, because the need for it was not recognized, due to the fact that the communication regarding WOs was done by the excel logbook.

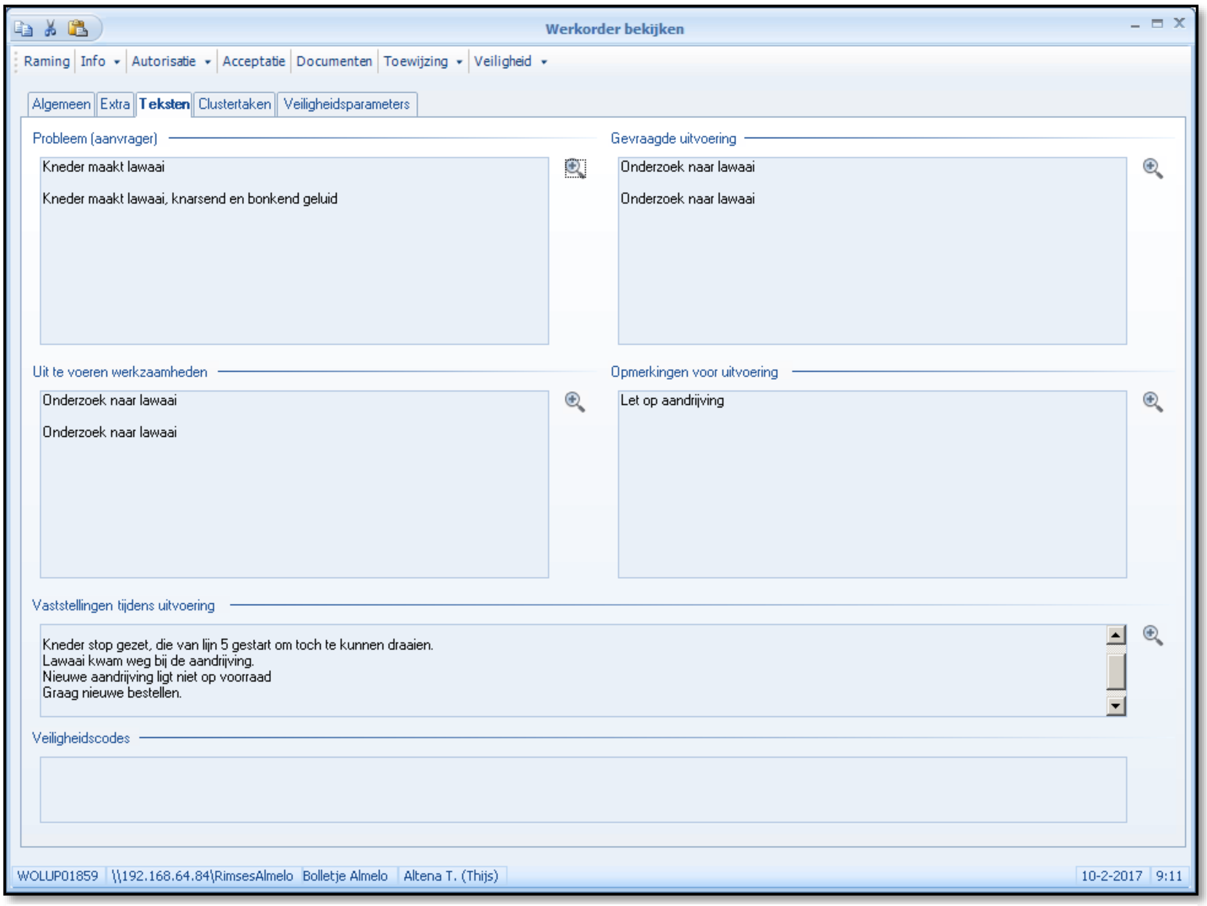


Figure 5.5: New WO, tab "Teksten"

What is remaining is that you want to show the performed WO in one clear overview. We achieved this with the help of ‘Report Manager’. Report Manager is a program which can be used to retrieve reports from databases like Rimses. Note that Report Manager is not a part of Rimses, but a stand-alone program. We used this program to automatically retrieve the following fields from the Rimses-database that are necessary information for in the logbook (also see Figure 5.6):

- Location
- Object (machine)
- Work type
- Work description
- Description of what was executed
- Priority
- Date
- Start time
- End time
- Number of minutes
- WO number
- Executer

Dagrapport Bolletje

Datum	Start	Eind	Aantal min	WO nr	Locatie	Object	Werkomschrijving	Wat gedaan ?	Werktype	Prioriteit	Uitvoerder	Klaar?
Feb 9 2017	13:55	14:17	22	44501	Knacklijn 353	deegpomp	Schraper 353 diosna schraapt niet aan bovenzijde ,Boven 2...	Schraper 353 diosna schraapt niet aan bovenzijde , Boven 2.5mm verzet	Storing	Prioriteit 1 (direct)	Steege Ter A.J. (Arjan)	Uitgevoerd
Feb 9 2017	13:44	13:47	3	44500	Palletiser lijn 4/5	Robot 3-4-5	Robot bek krom ,Bek gericht	Robot lijn 4 bek heeft pallet geraakt en is krom , Bek gericht	Storing	Prioriteit 1 (direct)	Steege Ter A.J. (Arjan)	Uitgevoerd
Feb 9 2017	12:59	13:39	40	44498	Lijn 4	Keerapparaat voor zuigdepanner Lijn 4	Slipt	Zou te veel slippen, machine werkt naar behoren.	Storing	Prioriteit 1 (direct)	Gerresheim, R. van (Rutger)	Uitgevoerd
Feb 9 2017	11:39	11:43	4	44495	Lijn 605 (schuddebuikjes)	Melkpakmachine	Lekkage	Slang is te groot voor slangtule 6mm. 8mm slang gebruikt van Festo voor tijdelijke oplossing.	Storing	Prioriteit 1 (direct)	Gerresheim, R. van (Rutger)	Uitgevoerd
Feb 9 2017	10:05	11:51	106	44496	Knacklijn 353	Zaagmachine 424.20	Zaag tafel 353 stuiterd terug ,Cilinders afgesteld	Zaag tafel 353 stuiterd terug , Cilinders afgesteld	Storing	Prioriteit 1 (direct)	Steege Ter A.J. (Arjan)	Uitgevoerd
Feb 9 2017	08:37	08:41	4	44488	Knacklijn 353	Kartoneermachine (Langen) 624.02	CE doosjes kapot	Ce doosjes kapotgedrukt, geleider afgesteld.	Storing	Prioriteit 1 (direct)	Gerresheim, R. van (Rutger)	Uitgevoerd
Feb 9 2017	08:28	08:36	8	44487	Knacklijn 353	Zaagmachine 424.20	Stopper\wegdrukker verwijderd	Stopper\wegdrukker weer verwijderd omdat deze de tafel te veel tegenhoud waardoor kapotte Knäckebröd bij invoeren. Deze komt dan tegen de geleiding aan.	Storing	Prioriteit 1 (direct)	Gerresheim, R. van (Rutger)	Uitgevoerd
Feb 9 2017	07:53	08:10	17	44486	Lijn 4	Metaaldetector	Gasveer defect van beschermkap, vervangen	Gasveer defect van beschermkap, vervangen.	Storing	Prioriteit 1 (direct)	Gerresheim, R. van (Rutger)	Uitgevoerd
Feb 9 2017	06:05	06:23	18	44485	Palletiseren / Robot Banket	Pallet Wikkelaar	Pallet uitvoer robot banket van slag af	Na handmatig weghalen van pallet is een sensor geraakt waardoor deze de reflector niet zag	Storing	Prioriteit 1 (direct)	Kolk, M.G.J. van der (Maarten)	Uitgevoerd
Feb 9 2017	03:14	05:03	109	44451	Lijn 6	Bakoven L6	gaskraan brander nakijkenh	De ander gas kranen ook gecontroleerd ,vervangen en afgesteld. Met onderhoud verstandig om alle kranen te wisselen voor gereviseerde.	Reparatie n.a.v. Inspectie	Prioriteit 3 volgens planning	Young, P.A. (Paul)	Uitgevoerd
Feb 9 2017	00:54	01:11	17	44484	Lijn 605 (schuddebuikjes)	Melkpakmachine	Variopack had geen vrijgave van robot	Variopack had geen vrijgave van de Robert pack aanvoer stond uitgeschakeld bij Robert pack	Storing	Prioriteit 1 (direct)	Kolk, M.G.J. van der (Maarten)	Uitgevoerd

Figure 5.6: The new Logbook

Further there are also different kinds of filters visible above the report:

- Start Time
- End Time
- Location
- Object (Machine)
- Priority
- Executer
- Way of sorting

With this filter it also becomes very easy to retrieve performed maintenance information of a machine in a certain time frame.

Example

To exemplify the fact described above an example of this case will be shown below:

If we want to know what maintenance has been performed in the month February of all molders (Dutch: Kneder) we fill the following filters:

- Start time = 1 February
- End time = 28 February
- Object = Kneder (Molder)

As a result we will get an overview with all WOs which were assigned to the dough preparation within the month of December. (See Figure 5.7 below)

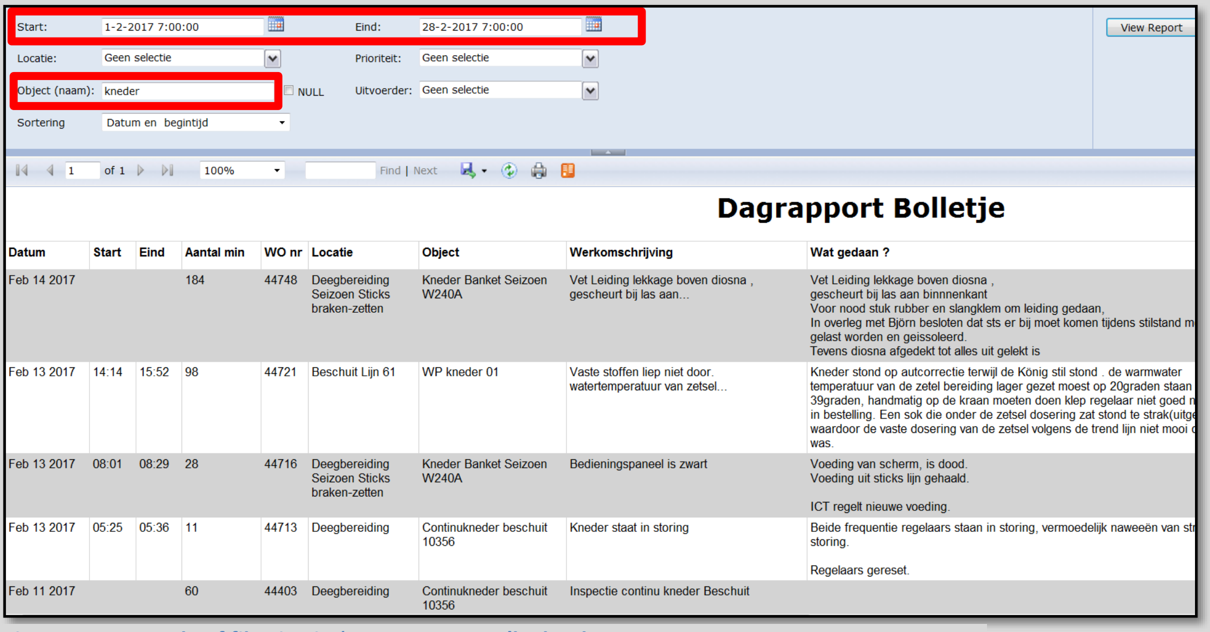


Figure 5.7: Example of filtering in 'Report manager'logbook

This Report Manager logbook is a summarizing projection of the data which is stored in Rimses. Therefore it is not possible to extract statistics from this logbook. This is only possible in Rimses, because within Rimses the data is stored as a database and not as a report.

5.4. Inventory management

As said in 1.3.2 the warehouse manager waits with putting a part 'on-stock' in Rimses until the invoice arrives. This results in never having real-time representation of your stock, because in the time between delivery of the part and invoice the opportunity arises where the stock level differs from its true value.

This can easily be solved by using the tool 'invoice registration' which is present within Rimses, but is not used at this moment. With this tool a separation is made between the registration of delivery and registration of invoice, which takes away the problem of registering the part only after the invoice has been received. However this change of working method will have major consequences for the entire warehouse management. The main problem for this is how the accounting system communicates with Rimses. To use this invoice registration, the accounting system needs to be linked on this invoice registration module instead of the 'delivery registration' module which it is linked to at this moment.

Due to time limit and the complexity of this problem this will not be further taken into account during this research, but it is seriously recommended to research this change of inventory management in further research. A very large problem regarding number of 'stock outs' and lack of inventory insight can namely be eliminated when it is chosen to use the invoice registration module.

5.5. Conclusion

In this chapter we found an answer to sub-question 5: *How should the registration of maintenance activities be organized so that it is value-added for making a preventive maintenance plan?*

This can be divided in the following sub-answers:

- Structure the 'machine overview' in the Rimses to improve logic and clarity.
- Control maintenance registration with the help of the available Rimses-app to ease the registration process and stimulate complete and accurate registration.
- Automatically retrieve logbook from Rimses database, which is filled with registration in the Rimses-app.
- Make use of invoice registration to improve the inventory management.

6. Creating a preventive maintenance plan

In the conclusion of our literature research we concluded that to answer sub-question 6: ***"What steps should the TD follow towards a successful preventive maintenance plan?"*** the best option to choose for was a combination of FMECA and Maintenance policy decision method. In this chapter we will show the recommended procedure to follow for creating a preventive maintenance plan. This will start with an explanation of FMECA, followed by the maintenance policy decision method.

6.1. Composition and quantity of FMECA sessions

The TD manager set a deadline that within a year a total preventive maintenance plan is developed for the newest section in the factory called 'Hal 16'. In this section there are two knäckebröd and one beschuit production lines. All three production lines can be divided into different sub-processes (as our running example 'Dough preparation' is one of them). It will ask too much time from the employees participating in the FMECA sessions to carry out FMECA for each particular component in the three production lines. The employees participating in the FMECA will namely have to do this besides their regular work and this time availability is limited. That's why in the first instance it is chosen that for each sub-process only the important machines and systems will be selected for the FMECA. This consideration is executed by a maintenance engineer, a process engineer and the manager TD so that these choices are made based on as much knowledge and experience as possible. For our running example one of these important machine of system is the molder'. Note that the molder is a sub-system of the 'dough-preparation' system (see Figure 5.1). This molder-example will be further used in the FMECA method explanation in section 6.2.

The FMECA sessions will be held two times per week with a duration of two hours per session. This duration is determined in consultation with the TD manager and PD manager, because they had to decide how much time FMECA participants could spend besides their regular work. In the FMECA sessions we strive to have at least the following participant's disciplines/background:

- FMECA Facilitator
- Maintenance Engineer
- Failure mechanic
- Production operator

Where the FMECA facilitator is mainly present to guide the FMECA session and to control the continuity of the FMECA process and the other three disciplines are present to have the right experience regarding severity, occurrence and detection.

6.2. FMECA itself

In this section, we will show how we applied FMECA on the hand of our running example shown in Figure 6.1.

6.2.1. Failure modes

The FMECA starts with identifying the failure modes for the machine or system that is chosen. According to Kmenta & Ishii (2000) the definition of a failure mode is:

"The manner in which a component, subsystem, or system could potentially fail to meet the design intent. The potential failure mode could also be the cause of a potential failure mode in a higher level subsystem, or system, or the effect of a lower level effect"

In the first FMECA session wherein our 'running example' the molder as seen in Figure 6.1 was discussed this resulted in two failure modes: 'engine not running' and 'transmission not functioning'.

6.2.2. Failure cause

"The FMEA has the ability to relate each Failure Mode to its Root Causes and then calculate the frequency of occurrence for each Root Cause" (Arabian Hoseynabadi, 2010)

Because of what is stated above it is chosen that for each failure mode also the root causes for the failure mode needs to be identified. These can be seen in Figure 6.1 and are split up in two different category, namely electrical (EMR) and mechanical (MECH). These possible failure causes are at this moment determined on the hand of the experience of the participants. But now that we have accurate maintenance activity registration as discussed in chapter 5, in the future, the maintenance that is registered in Rimses for this particular machine can be used as an extra input (not the only input) for possible failure causes.

6.2.3. Risk Priority Numbers (RPN)

Now that all the possible failure causes are identified it is time to determine its risks, dependent on its severity, occurrence and detection with the help of numbers of 1-10.

- For severity 1 means 'not serious' and 10 means 'catastrophic'.
- For occurrence 1 means 'almost never' and 10 means 'constantly'.
- For detection 1 means 'certainly' and 10 means 'very difficult'.

In the first FMECA session it is chosen for 1-10 instead of for example 1-5, because this would give them better opportunity to make difference between risks that lie close to each other, but definitely deviate. According the participant a ranking of 1-5 was insufficient suitable for these small deviations.

In the example one can see that for the failure mode 'engine not running' (In Dutch: 'Motor draait niet') all severities were 10. This is chosen because if the engine would fail, to complete production line would fail. For the failure mode 'transmission not functioning' (In Dutch: 'Overbrenging functioneert niet naar behoren') there were also two failure causes quantified with an 8. This is because in the situations of wear and leakage, the production line would not stop immediately, but would in short notice.

At this moment the frequency of these failure causes cannot be retrieved from Rimses yet. The last years Rimses has not been used accurate enough to draw conclusions from. If Rimses would be used as suggested in chapter 5 for at least one year, Rimses would be an accurate directory for determining the frequency number of the RPN.

Further one can see that for one of the failure causes ('wear', in Dutch: 'Slijtage') the eventual RPN had a value of 100. Automatically this RPN is colored yellow, while the other RPNs are colored green. Green means that no direct action is needed, but it could be useful to examine possibilities to lower its risk. Yellow means that in short notice research should be done how this risk should be decreased. If the RPN colors red, immediate action should be taken to lower the risk. When a certain RPN becomes yellow or red is dependent on the opinion of the FMECA participants. It also should not be seen as fixed determination. It could change in the future if is decided that these colors should have other spectra. At this moment RPNs until 85 are green, between 85 and 350 are yellow and above 350 are red.

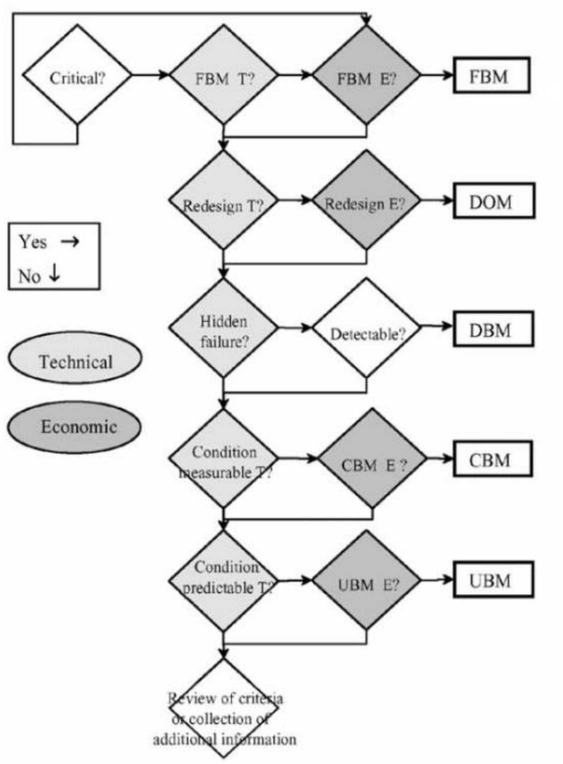
Now that we have determined the RPN numbers of each failure cause it is necessary to determine which maintenance policy should be chosen to lower this risk if needed. As said earlier the maintenance policy decision method is a useful method for this.

	Faalvorm Functionele verstoring	Faaloorzaak EMR	Faaloorzaak MECH	Ernst E De ernst (E) van het gevolg: 1-10 (niet ernstig tot rampzalig).	Kans O De kans (O) van opsporing: 1-10 (vrijwel zeker tot zeer moeilijk).	Frequentie F De frequentie (F) van de oorzaak: 1-10 (bijna nooit tot voortdurend)	Risico R Risico priority number	Onderhoud strategie Analyse uitvoeren voor geselecteerde rij	Actie
1	Motor draait niet	Aansturing PLC		10	1	1	10	Gebaseerd op falen	
		Aansturing Freqregelaar		10	1	2	20	Gebaseerd op falen	
		Beschadiging (kabels)		10	6	1	60	Gebaseerd op falen	
		Beveiligingen aangesproken		10	1	8	80	Gebaseerd op conditie	Jaarlijks controle beveiligings vvaarden
		Sluiting		10	1	1	10	Gebaseerd op falen	
		Overbelasting		10	1	5	50	Gebaseerd op falen	
			Slijtage	10	5	2	100	Gebaseerd op detectie	Productie controle op trillingen en geluid
			Te hoge temperatuur	10	1	1	10	Gebaseerd op falen	
2	Overbrenging functioneert niet naar behoren.		Slijtage	8	8	1	64	Herontwerp	Kosten bepalen temperatuurmeting
			Lekkage (olie / vvater)	8	1	2	16	Gebaseerd op falen	
			Te hoge temperatuur	10	5	1	50	Gebaseerd op detectie	Productie controle op temperatuur

Figure 6.1: FMECA for the molder in the sub-process 'Dough Preparation'

6.3. Maintenance policy decision method

As shown in section 3.2.5 the policy tree developed by Waeyenbergh & Pintelon (2002) is a useful tool to determine which maintenance policy should be followed depending on technical and economic question (see Figure 6.2 for repeat of Figure).



- **FBM:** Failure Based Maintenance.
- **DOM:** Design-Out Maintenance.
- **DBM:** Detective Based Maintenance.
- **CBM:** Condition Based Maintenance.
- **UBM:** Use Based Maintenance.

Figure 6.2: Maintenance decision policy tree (Waeyenbergh & Pintelon, 2002)

To make this better applicable in the Bolletje organization the tree is modified to make it better understandable (see Figure 6.3). This decision tree is incorporated in the FMECA excel-file (see Figure 6.1) with the help of a VBA-programmed tool. This is done in the following way:

- Select the failure cause we want to determine the maintenance policy for.
- Click the green button.
- A pop-up program opens starting with the first question of the decision tree with the possibility to choose yes or no.
- Depending on the answer the following question will show up in the program, again with yes and no as possible answers.
- This continues until one of the possible maintenance policies is chosen according to the decision tree.
- When a maintenance policy is chosen this value will be written to the cell under the green button and in the row of the failure cause.
- When no maintenance policy is possible, the program will delete all answered questions and restart with the first question. This is programmed, because we always want to choose a maintenance policy. (Take in mind that waiting till the part fails is also a maintenance policy).

What rests is determining what this maintenance strategy actual means in the form of actions. So could you see in our running example that for the failure cause ‘wear’ a ‘detection based maintenance’ policy is chosen. This translates to the following action: the production department is responsible for checking the engine for deviations in vibrations and sound.

Example

To exemplify the fact described above an example of this case will be shown below:

As seen in figure Figure 6.1 the failure cause ‘wear’ (In Dutch: Slijtage) has a RPN of 100. The maintenance strategy that is chosen is ‘Based on detection’ (in Dutch: gebaseerd op detective).

This maintenance strategy is the result of the maintenance policy decision tree shown in Figure 6.3.

- The first question ‘*is the part critical?*’ is answered with ‘yes’, because if the engine fails due to wear the production line will not create output. So we move one question to the right.
- The second question ‘*Can we technically wait till the part fails before replacement’ is anwered with ‘no’*, because there is a big technical risk that the complete engine irrevocable will fail, when it fails due to failure cause ‘wear’. This will have large impact on the production line, because there is no spare engine on stock. So we move one question to below.
- The third question *‘Can we technically redesign the part to make maintenance easier or eliminate it?*’ is also answered with no, because the engine is not engineered to cope with redign. That’s why we move one to the question below.
- The fourth question is ‘*Is there a hidden failure’*, which is answered with yes. There is a hidden failure because the possibilities of ‘wear’ in the engine are all not visible directly. So we move one question to the right.
- The fifth question is ‘*Is the failure detectable by human senses?*’ is answered with yes. It is namely possible to control the engine on deviant vibrations and noise. That’s why we move to the right: The maintenance strategy ‘Detective based maintenance (DBM) is chosen. The action linked to that strategy is: ‘Production checks engine for vibrations and noise.

All these possible actions together form the eventual preventive maintenance plan. Note that at first the determination of actions is based on the experience of FMECA-participators and eventually will be determined on the hand of Rimses-data. For our running example this would be:

- Engine: Yearly control of safety values and production checks for vibrations and sound for deviation
- Transmission: Redesign the transmission by adding a thermometer, so wear can be traced earlier and let the production control this temperature measurement.

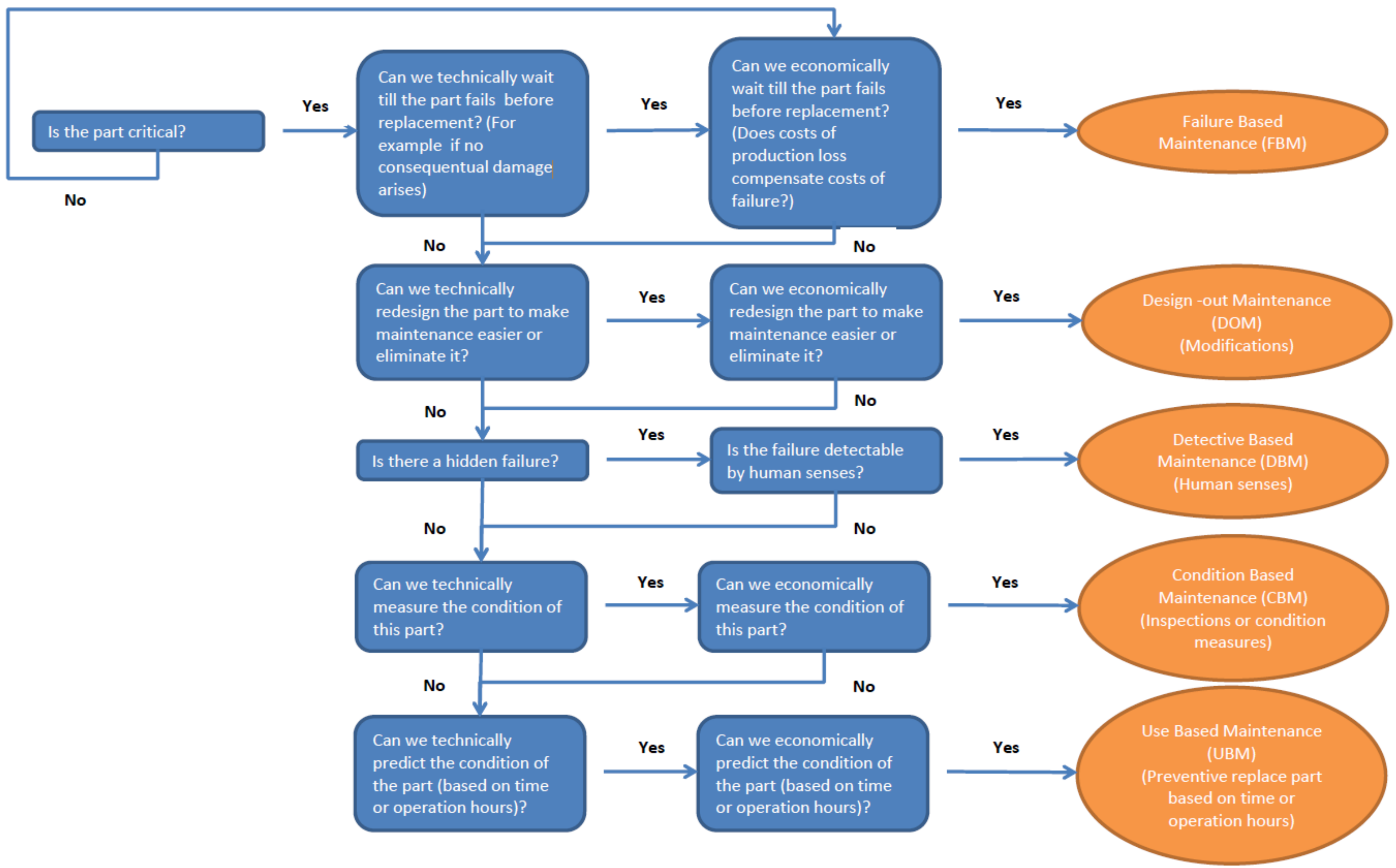


Figure 6.3: Maintenance policy decision tree Bolletje

6.4. Conclusion

In this chapter we found an answer to sub-question 6: *What steps should the TD follow towards a successful preventive maintenance plan?*

To create a successful preventive maintenance plan all critical machines and systems in all sub-processes of the three production lines needs to be analyzed with the help of the FMECA and Maintenance policy decision method. When this will be executed in the same way as the running example shown in Figure 6.1 and Figure 6.3 a complete preventive maintenance plan will be the result. Keep in mind that all FMECA documents are 'living documents', and needs to be updated if reality showed that the assessed risks are not accurate or the wrong maintenance policy was chosen. Further it is recommended to verify the FMECA files once per year to check if environmental changes within Bolletje have influence on the FMECA and maintenance policies.

When the three production lines in 'Hal 16' are finished it also might be needful to execute the prescribed manner at the other production lines at the Factory in Almelo, but also in Heerde. Take into account that it might not be beneficial to enter this program for production lines that will not be used for a long time (for example the 'oude beschuit'-lines).

7. Conclusions and recommendation

7.1. Conclusions

7.1.1. What is the current way of working within the Technical Department of Bolletje?

It can be concluded that the current way of WO registration is often incomplete and inaccurate. The registration in the logbook is very time consuming and does not create a database suitable for retrieval of accurate information based on machine, location or timeframe. Besides the overview machine structure in Rimses is not logical and confusing. The inventory management is inaccurate due to how Rimses is used.

Further the TD does not have any kind of performance measurement besides the fact that they strive to keep all production lines 'up and running' while staying within budget. The PD does make use their performance with the help of an OEE-toolkit. In sub-question 4 this appears to of value-added for the future performance measurement of the TD.

7.1.2. How should a Technical Department manage its maintenance activities and what is the best way to create a preventive maintenance plan according to literature?

As said in 3.2.3 "RCM is defined as a series of activities generated on the base of a systematic evaluation to develop or optimize a program of maintenance". This fits perfectly with the question of the TD how to create a preventive maintenance plan. For that reason the RCM method and in particular the methods FMECA and Maintenance policy decision method will be chosen to create a preventive maintenance plan in sub-question 6.

7.1.3. What Key Performance Indicators give a representative review of the performance of the Technical Department?

A meeting was held with the TD manager to decide which KPIs would give a representative review of the TD performance. The goal of this meeting was to have at least three defined KPIs at the end of the meeting, resulting in the following:

- Production line availability
- Preventive maintenance time / Corrective maintenance time
- Mean Time To Repair (MTTR)

The choice for three KPIs was made, because it is the first time KPIs are being used in the TD organization. Therefore, we chose for a cautious approach with a limited number of KPIs to ensure a good absorption in the organization with a possibility for extension in the future.

7.1.4. To what extent are the OEE statistics used by the Production Department a reliable source for measurement of these KPIs?

This question can be answered positively for the measurement of the KPI 'Production line availability' if the category 'quality' will be taken into account within the OEE-registration as discussed in 4.2.1. In that case the resulting percentage in the category 'availability' can be directly used as result for the 'Production line availability'-KPI. The OEE statistics cannot be used for the other two KPIs, simply because within the OEE no information is stored regarding preventive / corrective maintenance and because the malfunction registration does not accurately register the mean time to repair. The information for these two KPIs can be directly extracted from the Rimses database.

7.1.5. How should the registration of maintenance activities be organized so that it is value-added for making a preventive maintenance plan?

It can be concluded that to register all maintenance activities in an efficient and complete way the following cases have to be executed:

- Structure the 'machine overview' in the Rimses to improve logic and clarity.
- Control maintenance registration with the help of the available Rimses-app to ease the registration process and stimulate complete and accurate registration.
- Automatically retrieve logbook from Rimses database, which is filled with registration in the Rimses-app.
- Make use of invoice registration to improve the inventory management.

7.1.6. What steps should the TD follow towards a successful preventive maintenance plan?

To create a successful preventive maintenance plan all critical machines and systems in all sub-processes of the three production lines needs to be analyzed with the help of the FMECA and Maintenance policy decision method. When this will be executed in the same way as the running example shown in Figure 6.1 and Figure 6.3 a complete preventive maintenance plan will be the result. Keep in mind that all FMECA documents are 'living documents', and needs to be updated if reality showed that the assessed risks are not accurate or the wrong maintenance policy was chosen. Further it is recommended to verify the FMECA files once per year to check if environmental changes within Bolletje have influence on the FMECA and maintenance policies.

When the three production lines in 'Hal 16' are finished it also might be needful to execute the prescribed manner at the other production lines at the Factory in Almelo, but also in Heerde. Take into account that it might not be beneficial to enter this program for production lines that will not be used for a long time (for example the 'oude beschuit'-lines).

7.2. Recommendations for further research

7.2.1. KPI Dashboard

With the measurement of the three KPIs mentioned above a start can be made towards performance measurement of the TD. We recommend to monitor and show the KPIs in a place where each employee of the TD is triggered to increase the KPI results with the help of an interactive dashboard. You could think of a display in Excel with the help of pivot tables and slicers. Then it is also necessary to create some sort of integration between the OEE-toolkit and Excel. When excel is not sufficient it is advised to research additional possibilities of dashboard displays in the form of professional KPI dashboard programs. After a period of three months of usage of the mentioned three KPIs a session should be planned to determine if this number of KPIs is of sufficient added value, and therewith if additional KPIs needs to be defined.

7.2.2. Invoice registration

The problem regarding the inaccurate stock levels in the inventory management can easily be solved by using the tool 'invoice registration' which is present within Rimses. With this tool a separation is made between the registration of delivery and registration of invoice, which takes away the problem of registering the part only after the invoice has been received. However this change of working method will have major consequences for the entire warehouse management. The main problem for this is how the accounting system communicates with Rimses. To use this invoice registration, the accounting system needs to be linked on this invoice registration module instead of the 'delivery registration' module which it is linked to at this moment.

This will not be further taken into account during this research, but it is seriously recommended to research this change of inventory management in further research. A very large problem regarding number of 'stock outs' and lack of inventory insight can namely be eliminated when it is chosen to use the invoice registration module.

7.2.3. Roadmap

The KPI dashboard and invoice registration combined with the already initiated use of the Rimses-app, change of OEE-usage and implementation of FMECA will transfer the TD's current corrective maintenance policy towards a preventive maintenance policy. The recommended actions for accomplishing a better TD-performance are listed in Table 7.1 and the suggested sequence of these actions is shown in Figure 7.1.

	Action	**Actor**
1.	Educate and supervise mechanics' registrations in Rimses-app on correctness and completeness of data.	Team leader
2.	Change the OEE-registration so that category 'quality' is used according to literature	Manager Production
3.	Display and monitor KPIs dashboard in Workshop	Team leader
4.	Execute FMECA for production lines: 61,353 and 350	Maintenance Engineer
5.	Set-up separation between 'registration of delivery' and 'invoice registration'	Master Thesis – student and Warehouse manager
6.	Educate TD organization about this new way of registration.	Master Thesis – student and Warehouse manager
7.	Re-determine stock levels and values (counting of current stock)	Warehouse-manager
8.	Classify spare parts according to classification method and select corresponding inventory control policy per class.	Master Thesis - student
9.	Process inventory control policy in Rimses	Warehouse-manager
10.	After a year, review FMECA: re-determine severity, occurrence and detection, with the data gathered with the Rimses-app as an extra input-variable	Maintenance Engineer

Table 7.1: Roadmap with recommended actions and corresponding actors

Figure 7.1: Sequence of the to follow steps shown in the Roadmap

8. Bibliographic

A Pintelon, L. M.-Y., & Muchiri, P. N. (2010). Performance measurement using overall equipment effectiveness (OEE): Literature review and practical application discussion. *International Journal of Production Research*, 3517-3535.

Arabian Hoseynabadi, H. (2010). Failure Modes and Effects Analysis (FMEA) for wind turbines. *International journal of electrical power and energy systems.*, 817-824.

Bolletje B.V. (n.d.). *De Oorsprong van Bolletje*. Retrieved september 8, 2016, from Website van Bolletje b.v.: http://bolletje.nl/over/de-oorsprong/

Chand, G., & Shirvani, B. (2000). Impelemtation of TPM in cellular manufacture. *Journal of Materials processing Technology*, 149-154.

Das, S., Datla, V., & Samir, G. (2000). DFQM - An approach for improving the quality of assembled products. *International journal of Production research*, 457-477.

Gurumeta, E. (2007). Reliability Centered Maintenance. *9th International Conference: Electrical Power Quality and Utilisation .*

Hicks, B., & Matthews, J. (2010). The barriers to realising sustainable process improvement: A root cause analysis of paradigms for manufacturing systems improvement. *International Journal of Computer Integrated Manufacturing, 23 (7)*, 585-602.

Kmenta, S., & Ishii, K. (2000). Scenario-bassed FMEA: A life cycle cost perspective. *Proceedings of DETC* (pp. 1-11). Baltimore, Maryland: ASME.

McKone, K., & Weiss, E. N. (1998). TPM: Planned and autonomous maintenance: Bridging the gap between practice and research. *Production and operations management, Vol. 7, No. 4*, 335-351.

Muchiri, P. e. (2010). Development of maintenance function performance measurement framework and indicators. *International Journal of Production Economics* .

Nakajima, S. (1988). *Introduction to TPM: Total Productive Maintenance.* Cambridge: Productivity Press.

Parmenter, D. (2007). *Key Performance Indicators.* Hoboken, New Jersey: John Wiley & Sons, Inc.

Peterson, T. E. (2006). *The Big Book of Key Performance Indicators.* Portland: Web Analytics Demystified.

Stoll, H. (1988). Design for manufacture. *Manufacturing Engineering*, 67-73.

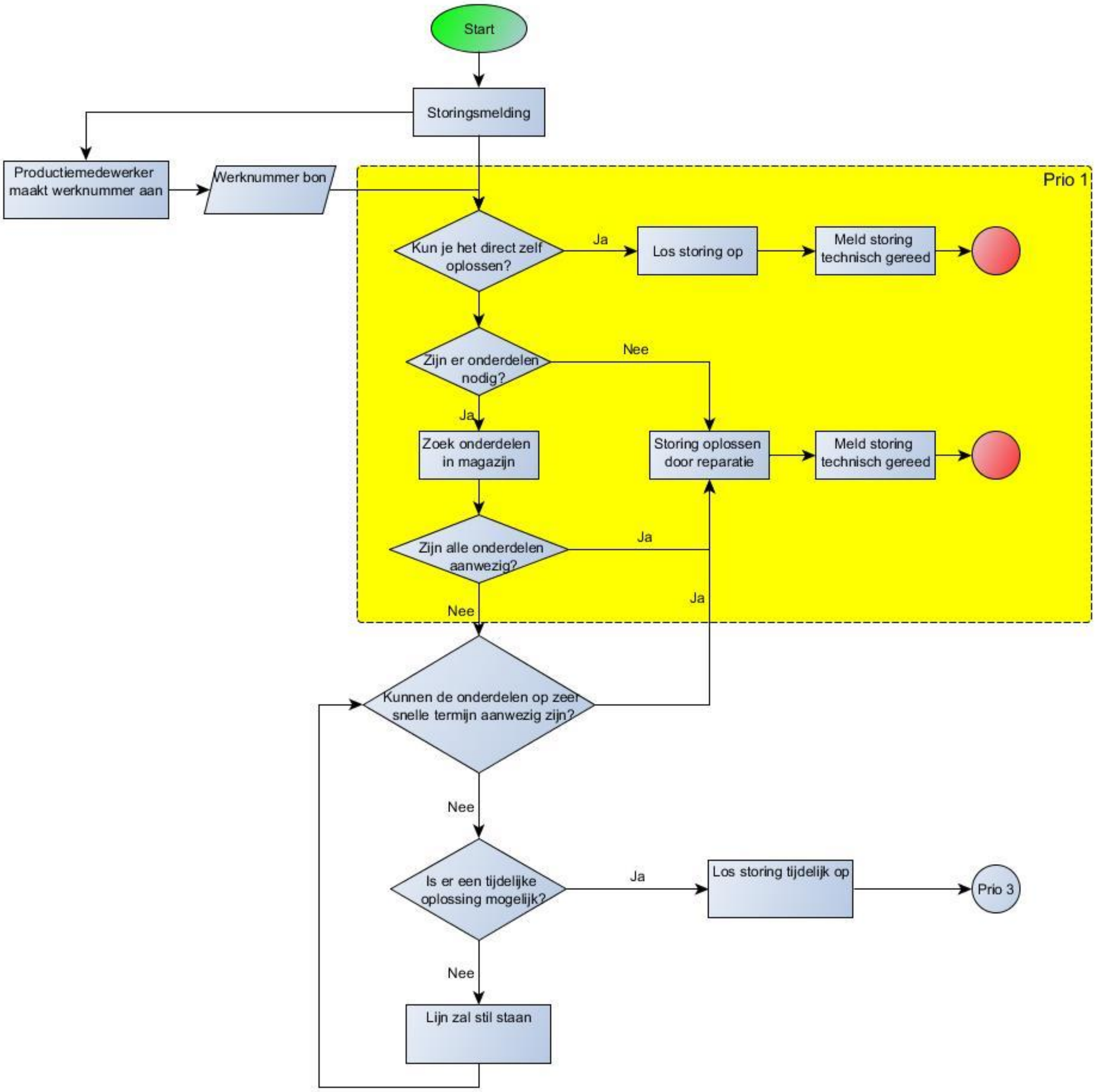
Tinga, T. (2012). *Mechanism Based Failure Analysis.* Den Helder, Netherlands: Nederlandse Defensie Academie.

Waeyenbergh, G., & Pintelon, L. (2002). A framework for maintenance concept development. *International Journal of Production Economics 77*, 299-313.

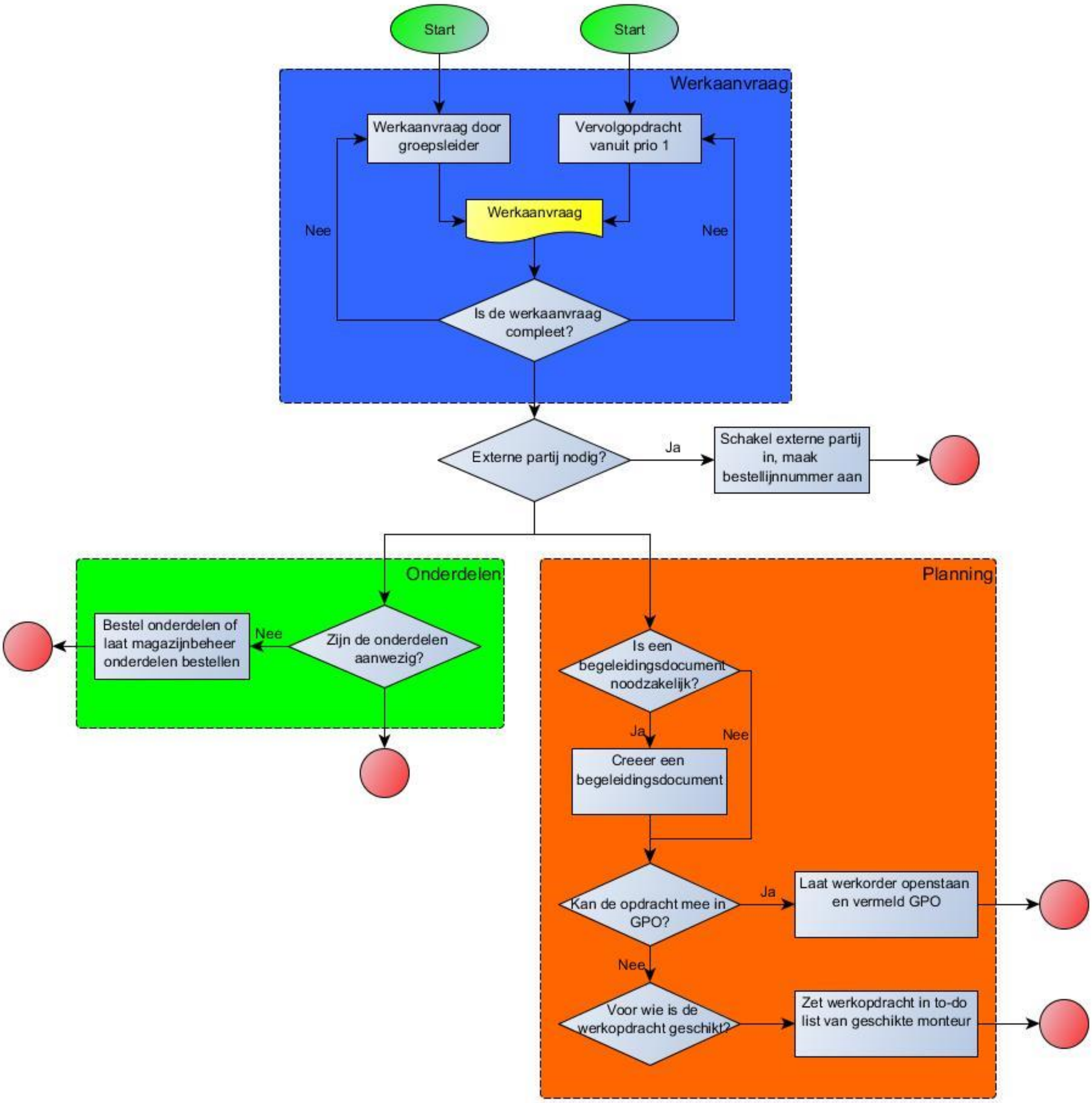
Weber, A., & Thomas, R. (2005). *Key Performance Indicators: Measuring and Managing the Maintenance.* Burlington Ontario: Ivara Corporation.

Appendix A: Flowcharts

Appendix A-1: The flowchart for handling prio 1 WOs



Appendix A-2: The flowchart for handling prio 3 WOs



Appendix A-3: The flowchart for handling Periodic Maintenance