TOWARDS THE OPTIMAL MAINTENANCE PROCESS ACCORDING WITH THE EN-17007 STANDARD

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Preface

Dear reader,

In front of you is my thesis written for my bachelor assignment of the study Industrial Engineering and Management at the University of Twente. The research is conducted at Catch22 in Eindhoven. I was welcomed into the company and was feeling good working there. They showed me everything in the company. I was able to learn a lot about maintenance and applied this knowledge to the already-known knowledge of business process modelling. I, therefore, want to thank the company and especially Jan Teun Koningen.

I also want to thank my supervisor from the University of Twente for her patience and great feedback. Lastly, I want to thank my family and friends for their unconditional support in the process of writing this thesis.

I hope you enjoy this thesis,

Dyon Kok, 21 January 2023

Abbreviations

ACT Carry out the actions needed for PRV or COR
BUD Budget maintenance of items
COR Restore the items in the required state
DOC Deliver the operational documentation
DTA Manage data
HSE Ensure the personal health and safety of individuals and preserve the environment in maintenance
IST Provide the needed infrastructure
MRQ Deliver maintenance requirements during items design and modification
OPT Improve the results
PRV Prevent undesirable events by avoiding failures and faults
RES Provide internal human resources SER Provide external maintenance services
SPP Deliver spare parts
TOL Deliver the tools, support equipment and information system
PVM Preventive Maintenance
CM Corrective maintenance

Management summary

Catch 22 is a consulting firm that specializes in providing guidance on maintenance processes for other companies. However, they struggle to determine what constitutes an optimal maintenance process. This research focuses on medium-sized companies and uses a fictional company as an example. The goal is to create an optimal maintenance process for these types of companies, following the EN-17007 European standard, which is commonly used in production companies. The research question is:

How can an optimal maintenance process be made for a medium-sized company in different levels of detail following the EN-17007?

A thorough review of the EN-17007 standard is conducted to identify the processes it outlines. The standard focuses on the management of the company's board and includes processes for corrective and preventive maintenance. These processes are then integrated into the overall maintenance job. These processes are supported by subprocesses, such as budgeting and spare parts management.

Next, the processes outlined in the EN-17007 standard are improved and adapted to fit the real-world situation with the input of experts from the company. These processes are then assigned to the appropriate maintenance personnel in the company, and reviewed by maintenance experts from Catch 22. Adjustments are made to ensure that the correct activities are assigned to the correct personnel. The model is then evaluated using maintenance maturity models, which are used to assess if a company meets the checklist. When all the boxes are checked, the model is considered fully mature and optimal. The model is then reviewed one more time with the help of these models and is ready to be tested in a case study.

The case study is conducted at two food production companies that are clients of Catch 22. An unstructured interview method is used to gather data. Consultants from each company were interviewed. The maintenance processes were presented and improvements were recommended for the documentation of one company, while the other company was provided with guidance on how to establish an organized maintenance process. Company X had many areas for improvement. In conclusion, the maturity level of Company Y is between 2 and 3, with room for improvement. The maturity level of Company X is between 1 and 2, with some areas at level 1 or even level 0 and others at around level 2. Level 0 is the lowest and level 5 is considered fully mature.

The maintenance processes in the final model have been positively evaluated by using maintenance maturity models and receiving feedback from maintenance experts. The different levels of the maintenance process can be found in the top level of the collaboration model of the maintenance models, which specify the communication between all the subprocesses. This follows the EN-17007 standard's guidelines. The subprocesses are designed to support the two main processes: preventive and corrective maintenance. Clear communication and strategy allow companies to achieve an optimal maintenance process.

The model provides an understanding of the necessary maintenance processes for a company. The model is general and can be adapted to any company with some modifications based on the company's strategy. It is important for all the tasks outlined in the processes to be present in some form for the company to be considered fully mature in terms of maintenance. Through testing the model on two companies, the maintenance model was put into practice and advice was given to the companies on how they could improve their maintenance processes. The maintenance processes presented in this thesis serve as a guide for maintenance consultants and offer insight into what an optimal maintenance process should look like.

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1. Introduction

In this chapter, the introduction to the research that is conducted is given. First, background information is given about the company and the importance of maintenance. Next, the problem is described, and after this the research design and the research questions are formulated and discussed.

1.1 Background information

Catch 22 is a consultancy company that focuses on maintenance. The company members guide their customers in multiple ways. For instance, the consultants of Catch 22 can research the companies and give targeted advice. Moreover, they do coaching, training, and they can be present as interim operators within a company. In general, they want to relieve the company of their stress and discomfort.

Maintenance is the core business of Catch 22. The problem they face is that there are nowadays so many standards involving maintenance. Catch 22 does not know what the benefits of the standards are and do not have the proper resources to do this research. They are interested in developing an optimal maintenance process while still following the standards that come with maintenance. Therefore, the processes a company uses to execute maintenance will be researched.

Maintenance is present on a standard day for almost everybody. Fixing things with a bandage or screwing the screw just a little bit tighter. Maintenance is also present in a business company. The type of maintenance Catch 22 is focussing on, is the type of maintenance that is happening inside production companies. In these companies, there are a lot of moving parts. There can be thought of companies like Cosun Beets, which makes sugar, or Ausnutria, which is making baby food. In these companies, there are pumps, cutters, rotors, valves and other types of machines and materials. To keep the production going these machines need maintenance. This is needed to not have high cost in replacing the whole machine. To perform maintenance, two types of maintenance will be focussed on.

It is important to distinguish between Preventive Maintenance (Adams et al.) and Corrective Maintenance (CM). PM and CM are differently addressed. As stated in preventive maintenance, PM will be used to prevent a problem from happening. In this case, maintenance is performed to repair a pump or a device so that it will not break down and avoid the whole process from shutting down. This will cost most of the time a lot of money. In PM, the repairs are planned, and, in this way, you have a planned downtime. This is cheaper than waiting for the device to malfunction. So PM is an important part in the maintenance processes (Peinado Gonzalo et al., 2022). For Catch 22 it is important to look at the different processes that come with PM.

Corrective maintenance is as the word says correcting a problem when something is broken. This type of maintenance is used when repairing the device and is more expensive than changing the whole device when it breaks down. This includes the cost that the time brings with it. Most of the time, CM is used when there are more machines per line, and when it is possible to switch between these machines. Thus, when one of the machines breaks down, the products can still go through the other machine. This will not result in a shutdown and so will result in no shortage of products and therefore have fewer extra costs. Addressing both PM and CM means that different processes are needed within a company. There are different people involved and different priorities for each of these types of maintenance. PM and CM processes are investigated and an optimal process considering both types of maintenance is designed. In section 1.2, the problem is explained in more detail.

This research focusses on medium-sized companies because most of Catch 22's clients are of this size. The expansion to a larger company or scaling down to a smaller company will be easier if the starting focus is medium-sized companies. Since this research is not based on a real company assumptions are made. A medium-sized production company has multiple production lines. According to the CBS, a medium size company has between 100 and 500 employees (CBS, 2022). Furthermore, there is a maintenance team in the company that consists of the following team. There is a maintenance team of technicians consisting of 40 people (Wireman, 2004). Above these ***maintenance technicians***, there is a management structure that includes a ***Planner*** and a **Scheduler**. The goal is that every function will be represented in a medium-sized company. As said before the decision can be made to scale up or down to match the size of the company.

1.2 The problem

Figure 1 shows the problem cluster, the problems and benefits are indicated on the right side. The improvement approach that is used can be seen on the left. Therefore, the problem cluster of the company is the part beneath the processes inside Catch 22. The problems that are tackled, the benefits are not clear, and Company does not know how their maintenance processes will look like.

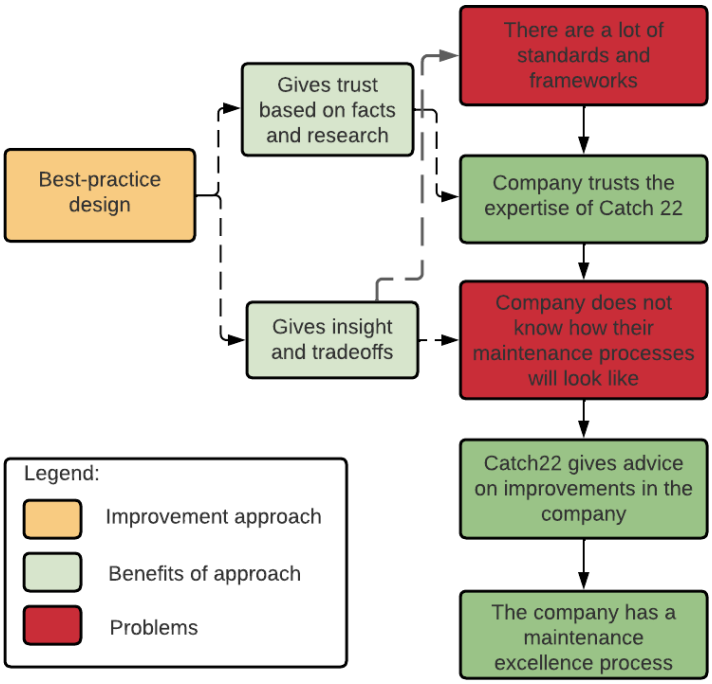

Figure 1 Problem cluster showing the current situation in Catch 22

1.2.1 Problem identification

There are a lot of norms and standards which maintenance needs to fulfil. There are standards for each country, for Europe and even internationally. It differs a lot from which standards a company will most benefit to use. It is not clear what the benefits are for the different standards. Next is that a company does not know how its business will evolve when they are improving its maintenance processes. There is no clear checklist to evaluate the maturity in handling their maintenance for the clients of Catch 22. Another problem to tackle is that it is not clear what the important factors are for having an optimal maintenance process. These are the main issues motivating this research. Therefore, this project's core problem is:

Catch 22 has no model for an optimal maintenance process

In Catch 22, there is a lot of knowledge and experience from working as a consultant or interim manager in factories for providing advice according to maintenance. However, the company is unable to do this type of research itself because they do not have the available literature that might be needed to provide a solution to the problem. They especially lack the expertise in using information systems and business processes to look into these problems and provide insights and solutions to them.

Now that the problem is identified, the *norm* and the *reality* can be defined. The *reality* is that there is now no insight into how an optimal process, a fully mature maintenance process (Oliveira et al., 2019; Tortora et al., 2022), looks like and what resources are necessary to execute that process. Furthermore, the benefits of having maintenance processes are not clear. The *norm* is having an optimal maintenance process which follows a standard in detail. This project follows the EN-17007-2017 standard (BSI, 2017), which is a European standard for maintenance processes. The company wants to use this to fulfil both the needs of the clients and their own needs. It is not clear what is included in this standard and why this can be useful. So, the norm includes knowing what parts of the standard are relevant for defining the optimal maintenance process. In other words, this research provides insights into the use of the selected standard.

1.3 Problem solving approach

For the problem-solving approach, the Design Science Research Methodology (DSRM) is used. As stated by (Peffers et al., 2007): “Artifacts are potentially constructs, models, methods, or instantiations or new properties of technical, social, and/or informational resources. Conceptually, a design research artifact can be any designed object in which a research contribution is embedded in the design.” This type of methodology is used because DSRM focuses more on delivering an artifact whereas the Managerial Problem-Solving Method (MPSM) (Heerkens et al., 2021) focusses on delivering a solution. The main artifact in this research is the optimal maintenance business process. There are several phases in the DSRM method. In Figure 2 all the steps of the DSRM are shown. The problem identification, the definition of the objective of a solution and the development and design of the artifact are described in this research.

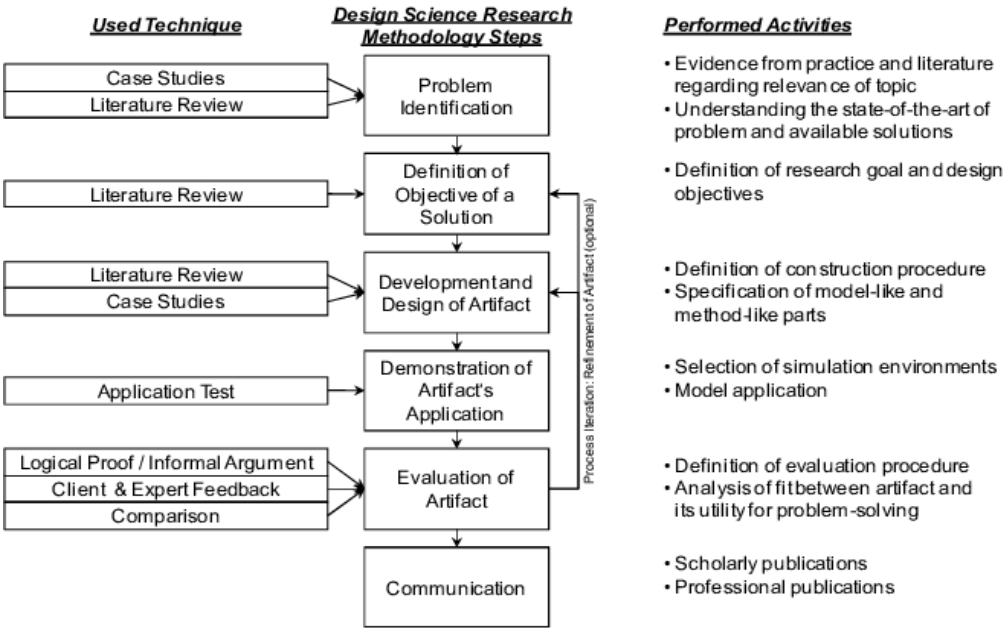

Figure 2 DSRM method (Jansz et al., 2011)

The following main research question has been derived from the core problem stated in Section 2.1:

How can an optimal maintenance process be made for a medium-sized company in different levels of detail following the EN-17007?

This research question is refined in a list of more specific research questions, as follows:

1. *What are the assets and activities in a maintenance process according to EN-17007?*
2. *How does Catch 22 as-is maintenance business process model look like?*
3. *How would an optimized to-be maintenance business process model compliant with EN-17007 look like?*
4. *How is the optimized to-be maintenance business process model evaluated?*
5. *How well does Catch 22 customers' maintenance process fit concerning the optimal business process?*
6. *What are the recommendations to improve Catch 22 customers' maintenance process based on the optimal business process?*

Phase 1: Problem identification

This phase is already addressed but more research is being done to understand more about the solution. Besides, this research investigates the different assets that are present in medium-sized sized companies. For clarity, the maintenance process is not of Catch 22 itself. This is because this is a consultancy company. The maintenance process is a generally usable model of a maintenance company. For this, an estimation is made on how the production plant looks like and the according numbers of staff. Problem identification is done via unstructured interviews and with the use of literature.

Phase 2: Definition of objective of a solution

To come to a solution, questions 1 and 2 above are responded to. These questions are necessary to support the optimal business process modelling, also clarifying which level of detail is needed for the

resulting business process model. The specifics of a maintenance process are used to address the different trade-offs and to subsidise the decisions regarding the resulting business process.

Phase 3: Development and design of the artifact

In this phase, the focus is on developing the to-be maintenance business, thus responding to question 3 above. Here, an interview is provided to support consultants in determining the level of maturity of Catch 22 customers. The maturity of a company is meaning how well a company is fulfilling the requirements of having a Total productive maintenance process. To know which conditions the model needs to fulfil, this research investigates the specifics of what constitutes an optimal maintenance business process. In this case, it is important to consider the costs of maintenance and the level of detail necessary for the resulting business process.

Phase 4 and 5: Demonstration and evaluation

Questions 4, 5 and 6 above are responded to during the demonstration and evaluation phases, which are combined in this research. First, it is important to identify the current state of the customer. This is done with an unstructured interview with the experts at that company. Then, some recommendations are elaborated to support them in reaching what is specified in the optimal maintenance business process model.

Table 1 shows the main objective for each question, the criteria to verify, the data-gathering method and the associated deliverables.

Table 1 Action table on research

Questions	***Objectives***	***Criteria***	***Data gathering***	***Deliverables***
What are the assets and activities in a maintenance process according to EN-17007?	*List and argumentation on including or excluding maintenance processes*	*Checked with experts for covering an average company. Conclude on argumentation and time consumption for the modelling phase.*	*Literature review*	*List*
How does Catch 22 as-is maintenance business process model look like?	*Literature on how the model looks like.*	*Checked with experts at the companies for the accuracy of the model*	*Literature review, Unstructured interview*	*As-is model. Report part on choices*
How is the optimized to-be maintenance business process model evaluated?	*Include EN-17007 and what is found in question 1*	*Includes all the important assets and activities from question 1. Checked with experts on the level of detail. Check with an expert on modelling for the modelling part.*	*Literature review, Unstructured Interview*	*To-be model. Report on choices*

How can the design be evaluated?	*Checklist or model that will be followed*	*Which type of review will be used?*	*Literature, expert's opinion*	*Checklist and method to use*
How well does Catch 22 customers' maintenance process fit concerning the optimal business process?	*Comparison between the optimal process and the real process*	*Experts' opinions.*	*Interview, questionaries*	*Interview results and summary*
What are the recommendations to improve Catch 22 customers' maintenance process based on the optimal business process?	*Recommendations*	*List with recommendations to which specifics of the optimal process to continue research in.*		

1.3.1 Deliverables

Three different kinds of deliverables:

- Five maintenance business process models, each one having a different level of detail. This starts with a level 1 business process, which provides an abstract view of the maintenance process; and it ends with a level 5 business process, which specifies in detail the maintenance process activities, including a thorough view of input and output data.
- A checklist to verify the maturity of the Catch 22 clients. This is done based on the aforementioned business processes. This checklist aims at providing the consultants guidance when dealing with clients.
- A report of the whole process, containing a business process model based on theory and expert opinion. There is also a recommendation and evaluation of the research to further develop this subject.

1.4 Research design

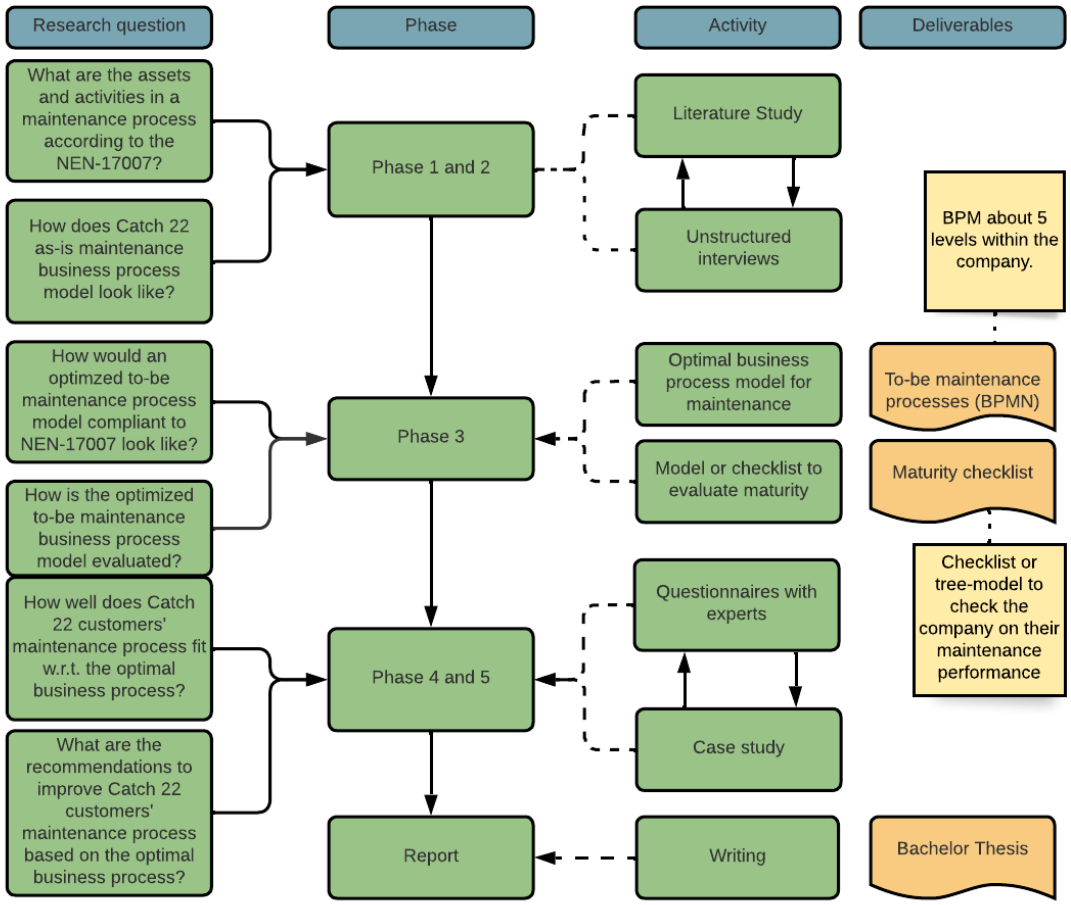

Figure 3 Research Design

1.4.1 Research type and subject

The research type is a literature study with a qualitative validation of the outcomes. After the literature study, the focus is on the designing and modelling of the processes. A model is designed to check the maturity of the maintenance processes inside a company. Therefore, an optimal maintenance process is developed based on theory. The research is descriptive for explaining how a model looks like and why and gives examples of how a process can look like. The research, therefore, business process modelling and experimentation to provide the optimal process.

1.4.2 Research subjects

The main research subject is the type of process and the level of detail. Furthermore, there is looked at the experts inside the clients of Catch 22. Therefore, the clients of Catch 22 will also be a research subject.

1.4.3 Key variables

The key variables that are used in the model are reliability, availability, and maintainability of the model. The control and reduction of the maintenance costs in the company. Developing the skills and preventing occupational accidents in the company. Overall equipment effectiveness is also a key variable in the process.

1.4.4 Theoretical perspective

The theoretical framework used for this research is the business process management domain. Business process management (BPM) is a discipline using various methods to optimize, improve and analyse business processes. In the research, the optimal business process for the maintenance process is looked for. The theoretical framework is therefore a logical choice. The need for insight into process of maintenance and to optimize this, is found in BPM.

1.4.5 Data gathering and analysis method

The data gathered is qualitative because most of the input is of an expert opinion. These inputs are used in order to compare the outcome and also to validate the final results of the optimal maintenance process. The data is also used to develop the problem identification.

Literature research

There is made use of literature research to answer the questions mentioned before. This is the basis of the answers to these questions. This method is used in phases 1, 2, and 3.

Data gathering unstructured interviews

Unstructured interviews are used to develop a clear sight of the problem and also in the process of developing the model. This is useful to have guidance at the beginning of the interview. This method will be used in phases 1, 2 and 3. This will help to develop a model with the input of the experts of Catch 22.

Content analysis

The content analysis in the unstructured interviews will be done according to looking back at the interview. There will be made notes to distinguish certain inputs of the interviewee and compare the results. This will help to summarise the outcome.

1.4.6 Validity and reliability

The assessment of validity and reliability of measurement is discussed in this section.

Internal validity

First of all, the internal validity of the research. When looking into the model is the result of looking at different types of theories about maintenance processes. There are many types of research already done but there is not looked into an optimal case. This research is deducting the best case based on the theory and knowledge of experts, by including both.

External validity

In the research is stated that this will work for medium-sized companies. The medium-sized company is defined on the forehand in order to guarantee external validity. This is to make sure that others can use my research when these criteria are met. An expert can look into my research and understand the outcome and influence when some factors of the company become bigger. This will result in different outcomes. By clearly stating these factors in the beginning others can use this in identical companies. My study is used by the consultancy company to show to their clients and use as an example of what is possible. There could be new insight into maintenance processes, but these could be included in the research by using the theory in the same way.

Reliability

The reliability of the study shows if the results are consistent. First of all, there can be looked at the stability of the measurement. This is not the case because only one input level will be measured for the companies. There are multiple opinions used when making the model but in the time frame that these opinions are gathered, there are no major impacts in the maintenance department. There were no new insights in making the business process model, so the stability will be sufficient.

The equivalence of reliability is an important part, this is guaranteed by performing interviews with the experts. The experts are interviewed individually. The results of these interviews are compared, to conclude a general opinion. When differences were noticed there is looked into the importance of this part in the research and another interview is considered. This was not necessary.

Problems in reliability to only ask the experts of the company. There could be a different result when asked to other experts. But the use will be in the company itself so if they agree on the model then there will be no reliability problems for the company itself.

1.4.7 Limitations of research design

The limitations of the research design are the opinions of the experts. Limited experts are working at Catch 22. Their opinions could be biased and therefore the validation phase in the process could be less valuable. This is because they will be consulted in the designing phase as the validation phase in the end. This is a limitation that needs to be watched and made clear in the process. A limitation could be that the interpretation of the gathered research could be different. This could be because there are guidelines for developing a maintenance process but no clear standards. The choice in focussing on some variables in this process can be a limitation. This is needed in order to be able to finish the project in the given time frame.

2 Theoretical framework

In this chapter, the theoretical framework is performed for use in the research. First of all, the Business process modelling is looked into to determine which type of business process modelling is most useful to use. Next, there is looked into the interview types to help with the interviews that are done later in the process. Finally, the way of evaluating the model is determined with the use of literature.

2.1 Business process modelling

For analysing the processes mentioned in EN-17007 and making models out of them, a business process modelling language is chosen. Different languages are addressed and finally, a choice is made. Different languages can be used for visualising process models (Weske, 2012).

Petri Nets

Petri nets are used to specify business processes abstractly and formally. Petri nets are abstract because they disregard the execution side in a process, the only thing that is covered is the functional and process perspectives. Petri nets consist of places, transitions and directed arcs connecting places and transitions. The Petri nets explain the static structure and the tokens move through making it a dynamic system. The current distribution of the tokens determines the state of the Petri net and the system modelled by it. It is mostly focused on the mathematical perspective, since it can provide mathematical formalisation (Weske, 2012).

Event driven process chains

Event driven process chains are important to model the domain aspects, instead of information provision (Weske, 2012). The language is on representing domain concepts and processes rather

than formal or technical realization. The building blocks are events, functions, connectors, and control flow edges. The events are happening in the process and are not guided by decisions. The symbols are clear and there is not a broad spectrum of splits and joins. The language is developed as part of the Architecture of integrated information systems (Dalmaris et al.)framework, which also covers other levels of abstraction regarding organisational business processes and strategies (Weske, 2012).

Workflow nets

Workflow nets is a language to enhance traditional Petri nets with concepts and notations that ease the representation. Workflow net introduces structural restrictions that are useful for business processes. The workflow nets focus on the control flow behaviour, the same as Petri nets. The activities of a business process are shown by transitions in the workflow net (Weske, 2012).

Yet another workflow language (YAWL)

Yet another workflow language is designed to support the control flow patterns. It is very similar to workflow nets and therefore to Petri nets. However, the duration of activities is represented by YAWL. (Weske, 2012)YAWL also is more specific on the types of joints, splits, and arcs between transitions. It has relatively few constructs and is therefore easily learnt (Hofstede et al., 2010; Weske, 2012)Hofstede et al., 2010; Weske, 2012).

Graph based workflow language

Graph based workflow languages are useful for implementing business processes, in which process activities are realized by software systems. The language was developed in the context of a commercial workflow management system. The input and output parameters can be graphed very well and linked to activities. Graph based workflow languages do not support arbitrary cycles, because, in cyclic process models, dead path elimination causes problems. Advanced control flow patterns are also not supported (Weske, 2012).

BPMN 2.0

BPMN aims at supporting the complete range of abstraction levels, from a business level to a technical implementation level. This goal is also laid out in the standards document, which states that “The primary goal of BPMN is to provide a notation that is readily understandable by all business users, from the business analysts that create the initial drafts of the processes, to the technical developers responsible for implementing the technology that will perform those processes, and finally, to the business people who will manage and monitor those processes (Weske, 2012).

There are many types of splits and joins and types of events, with each a different symbol. This means that is also not immediately clear how the process precisely looks. Furthermore, it is seen that often text is written next to these models to express the models better, this is because it has so many options that clarity must be provided sometimes. These texts can raise problems regarding consistency and reusability (Guizani et al., 2021). The language is good for representing the communication and collaboration between different instances. The data handling in a process can be represented by a data object. While the term data object seems to indicate digitalized information, it also covers physical objects, such as documents and products (Weske, 2012). In this case, the data object is used for example the tools or other items. This is done to give a better overview of the whole process. The items can be seen in Figure 4.

The elements of BPMN are divided into four categories:

1. Flow objects - building blocks of the business process

   a. Activities - objects that represent tasks of work executed during business processes.
   b. Gateways - represent join and split performance of the flow control
   c. Events - represent anything relevant that happens
2. Artefacts - show added information about the business process
   a. Data object - documentation and transfer of physical objects
3. Connecting objects - connecting the elements in the process
   a. Sequence flow - used for specifying the order of the flow
   b. Message flow - specify the flow of messages between pools
4. Swim lanes - represent a certain process

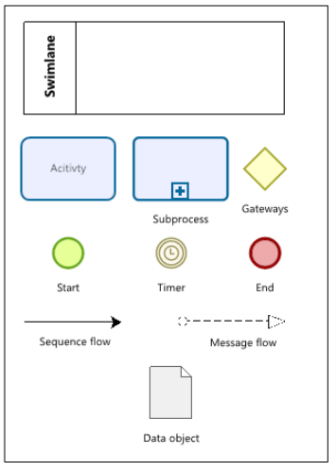

Figure 4 Items used for BPMN 2.0

2.2 Conducting interviews

In the research there will be interviews with employees of Catch 22. Conducting an interview requires first of all designing and planning. After this, the interviews can be conducted and then there must be made sense of the interview data.

First, there should be chosen between structured and unstructured interviews. The interview is the primary data collection technique for gathering data in qualitative methodologies. Interviews vary based on the number of people involved during the interview, the level of structure, the proximity of the interviewer to the participant, and the number of interviews conducted during the research.

The researcher chooses either an unstructured interview (no specific questions or order of topics to be discussed, with each interview customized to each participant; generally starts with a participant narrative) or a semi-structured interview (generally starts with a few specific questions and then follows the individual's tangents of thought with interviewer probes) or a structured interview (often uses a detailed interview guide similar to a questionnaire to guide the question order and the specific way the questions are asked, but the questions generally remain open-ended). Structured interviews permit more direct comparability of responses; question variability has been eliminated and thus answer variability is assumed to be real. Also, in the structured interview, the interviewer's neutrality has been maintained.

Most qualitative research relies on unstructured or semi-structured interviews. The unstructured and semi-structured interviews used in qualitative research are distinct from the structured interview in several ways. They:

• Rely on developing a dialogue between the interviewer and participant.
• Require more interviewer creativity.
• Use the skill of the interviewer to extract more and a greater variety of data.
• Use interviewer experience and skill to achieve greater clarity and elaboration of answers.

After that, the search start to the best way to analyse the data, here are different methods for it. When finding the best-suited method, the last step is writing all the interview data down (Rowley, 2012).

2.3 Maintenance maturity models

Maturity models have been widely developed in many fields of knowledge to improve organizational performance (Oliveira et al., 2019). A maturity model is a structured model based on five incremental levels of maturity for quality management in an organization called a Quality management maturity grid.

The analysis that is performed by Oliveira about the different maintenance maturity models (Oliveira et al., 2019), is a guide to how a maintenance maturity model should look and how a model can be developed. Furthermore, the analysis of what was in previous maturity models. The outcome of the first analysis can be seen in Figure 5. The stage/level is stated in the different models as well as the measurement classes. The measurement classes are increased in number because maintenance management became more important over the years.

Proposed by	Measurement classes	Level/stage
Antil (1991)	1. Management understanding and Attitude 2. Problem handling 3. Company maintenance posture 4. CMMS	1. Uncertainty 2. Awakening 3. Enlightenment 4. Wisdom 5. Certainty
Wireman (1992)	1. Corporate/plant management attitude 2. Maintenance organization status 3. Percentage (%) of maintenance resources wasted 4. Maintenance problem solving 5. Maintenance workers, qualification and training 6. Maintenance information and improvement actions 7. Summation of company maintenance position	1. Uncertainty 2. Awakening 3. Enlightenment 4. Wisdom 5. Certainty
Cholasuke *et al.* (2004)	1. Maintenance effectiveness (output) 2. Policy deployment and organization 3. Maintenance approach 4. Task planning and scheduling 5. Information management and CMMs 6. Contracting out maintenance 7. Continuous improvement 8. Financial aspects 9. Human resource management 10. Spare part management	1. Innocence 2. Understanding 3. Excellence
Campbell and Reyes-Picknell (2006)	1. Strategy 2. People 3. Work management 4. Materials management 5. Basic care 6. Performance management 7. Support systems 8. Asset reliability 9. Teamwork 10. Processes	1. Innocence 2. Awareness 3. Understanding 4. Competence 5. Excellence
Chemweno *et al.* (2015)	A. Strategic: 1. People and environment; 2. Functional and technical aspects; 3. Plant design life; 4. Support; 5. Maintenance budget B. Tactical: 1. Safety/risk/health; 2. Output quality; 3. Reliability; 4. Availability; 5. Inventory of spare parts; 6. Capital replacement decision; 7. Maintenance cost; 8. Overall equipment effectiveness; 9. Environmental impact; 10. Logistics; 11. Maintenance quality; 12. Personnel management; 13. Productivity; 14. Life cycle optimization; 15. Maintainability	1. Level 1 2. Level 2 3. Level 3 4. Level 4 5. Level 5

Figure 5 Maintenance maturity classification (Oliveira et al., 2019)

The analysis of the paper declares a new model, the maturity model is a tool that supports decisions and assists in the recognition of the current state. Maturity models are tools that support decisions since they assist in the recognition of the current state of the organization and promote the adoption of measures so that improvement actions are identified, implemented, and measured. The use of maturity models can lead to a positive spiral in maintenance management, preparing the organization for future steps to Maintenance management performance be given, around powerful

support systems based on best practices developed in the scope of organizational management (Oliveira et al., 2019). The proposed maturity model focuses on the improvement of the maintenance area, instead of being oriented to external benchmarking. The development of the model is done by performing a literature review and looking at previous maintenance maturity models. The model can be seen in the B.1 Maintenance maturity model 1 and is used in chapter 4 to test the maintenance processes made.

Another maintenance model is developed by Tortora (Tortora et al., 2022), this maintenance maturity model is focused on information management in maintenance management. The model provides a procedure for evaluating the current maturity level of maintenance information management practices (Tortora et al., 2022). The focus of this maturity model is on small and medium-sized companies. The model will provide and support the knowledge of the behaviours and practices for achieving world-class results. The model itself is not validated yet also the model is made general and not specified to an industrial sector. The model can be seen in B.2 Maintenance maturity model 2.

2.4 Evaluation of the design

The evaluation of the business process model is best to be looked at first from a broader perspective. It must be based on the different levels according to ISO standards. Among the elements that make up an asset management system, performance evaluation concentrates the monitoring, measurement, analysis, and evaluation. According to the ISO (2014b), the organization shall evaluate and report on the asset performance, the asset management performance, and the effectiveness of the asset management system. Therefore, performance evaluation takes place at three different levels (da Silva et al., 2020). These different levels should be addressed before looking into the models themselves but are needed to have a clear view of the concept that is needed.

The answers imply that the addition of more criteria and the different weighting for the criteria were 100 percent accepted and approved by the participants. Team members also agreed that direct comparison gives a better assessment of ranking failure modes (Filho et al., 2017). The comparison should be made with the earlier made as-is model of the processes. In this way, a clear comparison can be made, and differences can easily be addressed.

The proposed framework integrates Delphi methodology to obtain a consensus of specialists' opinions, an analytic hierarchy process (AHP) to perform multiple criteria-based risk assessments and a business process management system to instantiate the development cycle. A conceptual model is presented and analysed through a case study (Filho et al., 2017) Furthermore, the FMEA is used to make a clear evaluation of the already existing processes in the company. This is also needed to make clear statements about whether the improvements are found or not.

It is needed to remark at the end that a broader basis might be needed to validate. Moreover, while initial experiences with applying facets of our approach in industrial settings have been highly encouraging, a much broader empirical basis is needed for serious validation, especially of the simulation models (Jarke et al., 1997)

3 The maintenance process

In this chapter, there is looked at the maintenance processes according to the EN-17007. This is needed to understand which process should be used in the optimal processes in chapter 4. This chapter describes all the processes of the EN-17007.

1. *What are the assets and activities in a maintenance process according to EN-17007?*
2. *How does Catch 22 as-is maintenance business process model look like?*

3.1 Method

The new to-be maintenance process is the EN-17007 document. A lot of maintenance activities are referenced in this document or will be needed to be applied to this document. The document will be used as an artifact to build the model. The document will be analysed and the important processes in the maintenance process will be addressed and explained. There is looked into who is performing the tasks presented in the EN-17007. This will be discussed with the maintenance expert about details in parts of the maintenance process. The discussion focuses especially on who is performing each maintenance task.

3.2 Results

The EN-17007 is a document that describes how a maintenance process should look like. Companies could use this in order to say that they comply with these standards in maintenance management. This could be used in communication with their maintenance managers or companies that they will hire to perform maintenance to their plant or production facility. In the mapping of the different processes, there are 2 levels on how they can be mapped. Level 1 is the overall view of the maintenance process and level 2 is the more specific explanation of the maintenance processes. The level 1 and level 2 statuses will be indicated under the given figures.

The Maintenance process can be divided into three sections:

- The manage maintenance, where they set a goal and strategy for the company for their maintenance management.
- The actual maintenance processes are divided into preventive maintenance, corrective maintenance, and improvement management.
- The final section is the supportive processes. An overview of the processes can be found in Figure 6. This figure shows that all the different sections are connected and in total contribute to the maintenance of the whole company.

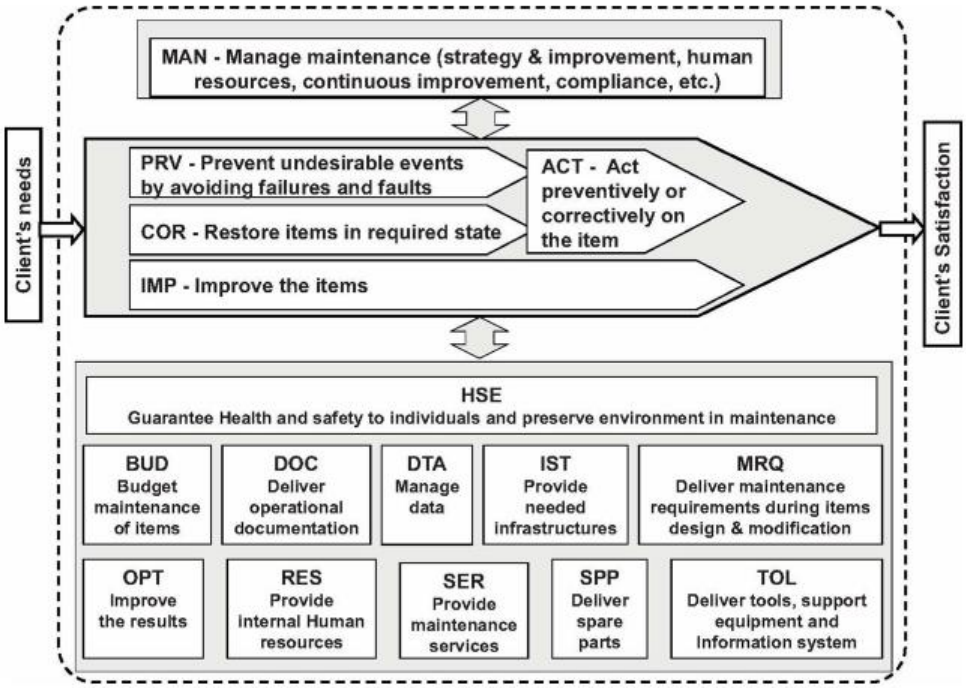

Figure 6 Maintenance process total overview (BSI, 2017)

Manage maintenance (MAN)

The manage maintenance section is about the policy, strategy, and development of these actions. A task in this process is to establish these policies, strategies, and development actions according to these. The total manage maintenance consists of the following processes, also depicted in Figure 6.

MAN.1 Establish the maintenance policy, strategy & development actions

A strategy needs to be developed where there will be made a prioritization of the safety of individuals and items. Furthermore, the availability and useful life of the items should be considered and finally the optimization of the costs in maintenance. This is mostly the policy that will be used by the company. Next is the strategy where choices need to be made in the following parts of a company. The development or implementation of maintenance methods, and the organisation of internal resources. The in-/outsourcing of the maintenance tasks and the economic impact of modifications or improvements on items in the company.

MAN.2 Identify the internal or external activities

The policy and strategy make it possible to identify maintenance activities that will be carried out internally and those assigned to participating companies. The connection between the budgeting department led the company to choose between making and buying the maintenance task.

MAN.3 Determine the organization, job profiles and responsibilities

Based on the strategy and policy the tasks and job profiles are established. This in combination with the possible need to update the present skills. The responsibilities are assigned to the company's personnel. Based on the direction and choices expressed in the policy and strategy, an organization is set up to determine its responsibilities.

MAN.4 Prepare and negotiate the budgets

Economic plans (budgets) are approved and adjusted by Management based on the budgeting process (BUD).

MAN.5 Oversee the actions

All the actions included in the maintenance process are coordinated, supervised and, if applicable, decided on by Management to achieve the goals and objectives defined in terms of safety, availability, costs, environment, quality, etc.

MAN.6 Define, select, analyse and communicate the information

The technical, organizational, economic, and social information that shall be communicated internally and/or externally is defined, selected, analysed, and made available to the relevant entities.

MAN.7 Define policy and strategy areas of improvement

All information (technical, organizational, economic, and social) is analysed to continuously adjust and improve the maintenance policy and strategy.

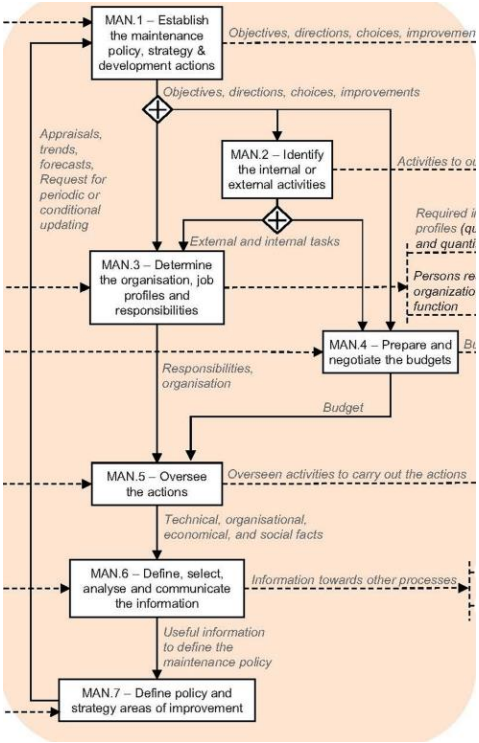

Figure 7 Management process (BSI, 2017)

Maintenance processes

The maintenance process can be divided into three sections namely the preventive maintenance, corrective maintenance, and improvement maintenance process. The preventive and corrective maintenance processes have different processes in the beginning but when they are performed, the preventive and corrective maintenance tasks or combined in a total process of ACT. Therefore, first, the specific tasks will be explained and after that, the performed tasks on the maintenance will be explained for both of them together. This can be found under the ACT part of the maintenance tasks as can be seen in Figure 5.

Preventive maintenance

The first process in preventive maintenance is to characterize undesirable events. After this, the maintenance plan is made or updated according to the new maintenance tasks.

PRV.1 Characterize undesirable events

In the task of characterizing undesirable events, certain key activities need to be performed. First a list of proven and/or potential events whose consequences on the issues at stake have been or may be significant. Next, the primary causes need to be analysed and documented. Then the effects of failure modes need to be identified. The failures that have led to a repair action or preventive restorations need to be compiled. The undesirable event needs to be analysed and there should be determined whether the event is hidden or apparent to the user. The final step is to prioritize the events based on their effects. The methods for detecting the failures can be done by following the industry 4.0 developments, with sensors and runtime detection.

PRV.2 Use and update the maintenance plans

Determine the feasible predetermined and/or condition-based preventive maintenance tasks, and their occurrence based on the number of units of use, which can prevent the causes of the undesirable events if it is economically acceptable (predetermined budgets). Considerations about the item improvements to reduce or prevent the causes of the undesirable events. Thereby it is important to look for a technically and economically advantageous improvement. Also, consider improvements in operating procedures or protection against the consequences that follow from undesirable events. All this is used to come up with a maintenance plan where the specific actions are stated to be performed. This will then be used in ACT.1 and ACT.2 to further perform the maintenance tasks.

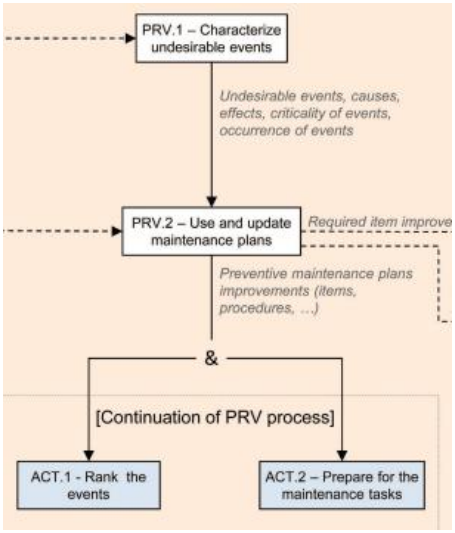

Figure 8 Preventive maintenance (BSI, 2017)

Corrective maintenance

The corrective maintenance is in action when a certain failure event comes up. The event should then first be classified and after this, the item needs to be diagnosed to determine the impact of the specific failure.

COR.1 Classify the events further to a failure

For the classification of the events, the following tasks need to be performed. Gather the actual events to be considered in the next given period and the data necessary for establishing priorities. Analyse the actual events to deal with and rank them by priority. Next, establish the first schedule for corrective maintenance.

COR.1 Diagnose the state of the items in question

Identify the item affected by the undesirable event and its environment. Identify the effects of the undesirable event on the item and its environment. Locate and identify the causes of probable failures. Look for a possible recurrence of the failure. Look for the primary causes of the failures. This will be used in ACT.2 of the maintenance tasks to be performed.

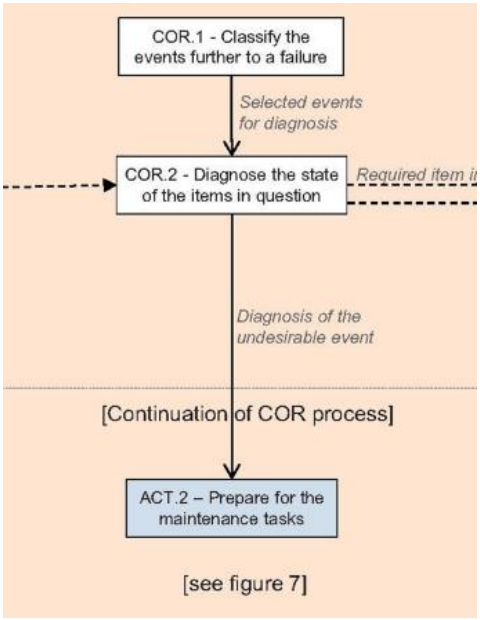

Figure 9 Corrective maintenance (BSI, 2017)

Performing the maintenance tasks

The maintenance tasks that follow from the preventive maintenance and corrective maintenance are performed in the described way in this section. The preventive maintenance flows in this process as said earlier in ACT.1 and ACT.2, whereas corrective maintenance only flows in the ACT.2 process.

ACT.1 Rank the events

The first part of performing a company's maintenance tasks is gathering all the events in the next given period. The data is collected for establishing the priorities. After this, the events to deal with are analysed and ranked by priority. Then a schedule is made to perform the maintenance tasks, and this is used as input in the next process.

ACT.2 Prepare for the tasks;

The process of ACT.2 is performed at almost the same time as ranking the events. In this process, the actions that follow from the preventive maintenance and corrective maintenance are prioritised. In this, the environment of the items on which maintenance is performed, is taken into account. This risk analysis is used as an input value for this process. The procedures to perform the maintenance tasks are updated, where it is stated the actions to be performed and the necessary resources.

ACT.3 Set in order the tasks

The tasks are set in order and the information is reviewed. Thereby there should be looked at the information regarding maintenance constraints and uncertainties. This is also important for the information about the use of the item and multiple maintenance requests about the same item. The operations to be performed are put in chronological order with all this taken into account.

ACT.4 Schedule the tasks;

The schedule of the task is drafted and the information about the use of the items is reviewed as well as the constraints and uncertainties related to timeframes and internal and external resources. Based on the order and constraints a schedule is made.

ACT.5 Begin the scheduled tasks;

Designate the maintenance personnel for each scheduled task who are competent and have the right

qualification. Manage uncertainties about maintenance tasks, personnel, and resources. The task can be started, and maintenance can be performed.

ACT.6 Perform the maintenance tasks;
Ensure the safety of the items and individuals (restrict the use of the items and access points, provide personal and collective protective devices). Conduct a “safety” inspection. Implement the means required to perform the task (site preparation). Follow the predetermined maintenance procedures. Check that the maintenance task has been completed and remove the restrictions relating to the items and access points. Check the proper operation of the item in its functional environment. Determine the actions to be taken to handle deviations (in functioning, in procedure, supports, etc.)

ACT.7 Finish the tasks
After the performance of the maintenance tasks, the task needs to be accepted. The maintenance area is restored, and the tools are returned. After this, the item is returned to the user (the machine can be used in production). A report is constituted with information about the maintenance task. Finally, the work order is closed.

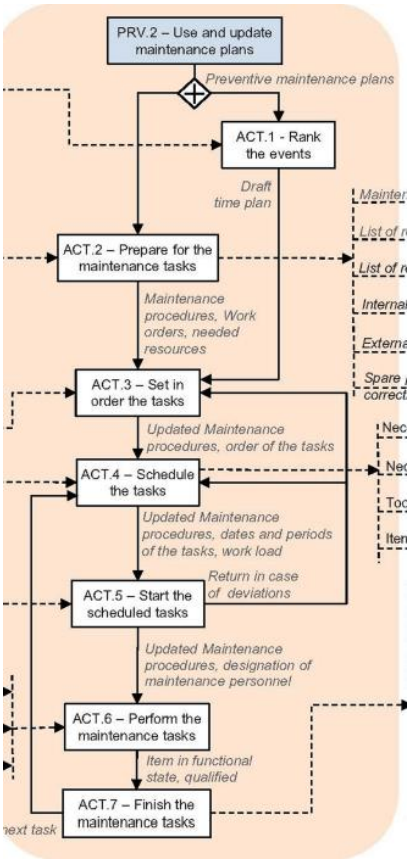

Figure 10 Act of the maintenance tasks (BSI, 2017)

Improvement process

In this part, the improvement process is described and the different tasks that are important to perform the improvements inside a company that is compliant with the ISO 17007 standards. This section is not of importance in the scope of this research and is, therefore, set aside.

Supportive processes

The supportive processes in the total structure of the maintenance process can be divided into 11 supportive processes. Each process will be individually addressed and the accompanying tasks. The

processes are the Health and Safety process, Budget maintenance of items (BUD), Delivery of the operational documentation, Data Management (DTA), Infrastructure (IST), Maintenance requirements (MRQ), Optimisation (OPT), Resources (RES), Services (SER), Spare parts (SPP) and Tools (TOL).

Health and Safety

The health and safety during the maintenance tasks is an important factor therefore the following processes need to be performed and used during the maintenance process.

HSE.1 Prepare the risk assessment

First, the scope of the action needs to be defined, after this the methods according to the information and regulations need to be identified. A multi-disciplinary group needs to carry out the risk assessment.

HSE.2 Identify risks

Identify the hazards of undesirable events and their consequences, and materials that are hazardous to personal health and the safety and the environment. Value the risk accompanying these events for individuals and the environment.

HSE.3 Prioritize risks

Evaluate the risks by describing the likelihood of occurrence, severity, and frequency of exposure of individuals. Classify the risks to discuss the priorities and plan preventive measures.

HSE.4 Propose measures for preventing risks and consequences of identified risks

Identify the technical and organizational measures, select, and implement the solutions and eventually evaluate the residual risks. This all needs to be documented.

HSE.5 Monitor risk management

Ensure compliance with regulations and develop a safety culture within the company. define, calculate, and analyse indicators to ensure proper risk management.

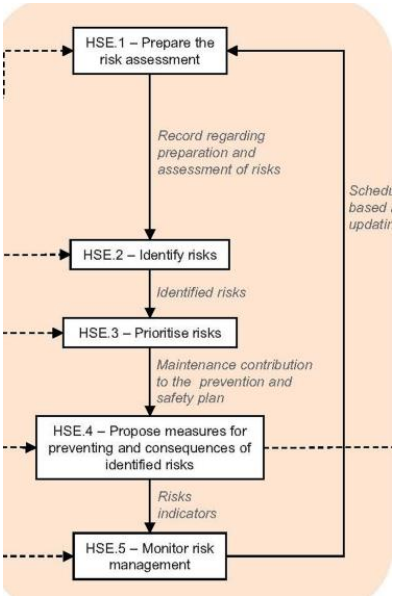

Figure 11 Health and Safety (BSI, 2017)

Budget maintenance of items (BUD)

Schedule economic planning based on a defined cycle, for regular maintenance and exceptional maintenance activities. This process is used to structure budget information, by cost allocation categories, to ensure that it is monitored, checked, and managed over time. The different processes that are accompanied by this process are described below and can be seen in Figure 12.

BUD.1 Define, compile cost elements and calculate or estimate actual costs
Cost elements are allocated, by the item, type of maintenance and destination.

BUD.2 Create a budget estimate for regular maintenance
The estimation for regular maintenance needs to be prepared per item over several accounting periods. This budget should also include common costs allocated to regular maintenance.

BUD.3 Create a budget estimate for infrequent or exceptional maintenance tasks
The budget estimate for infrequent or exceptional tasks is prepared per item for all items. This budget includes common costs allocated to exceptional maintenance.

BUD.4 Extract budgeted and actual expenditures
The budgeted and actual expenditures are documented per item. These are then compiled and classified for effective analysis.

BUD.5 Analyse, explain and, if applicable, take corrective actions
Deviations between budgeted and actual expenditures are detected, analysed, and explained. Any corrective actions are identified and the results of these analyses are sent to management for decisions.

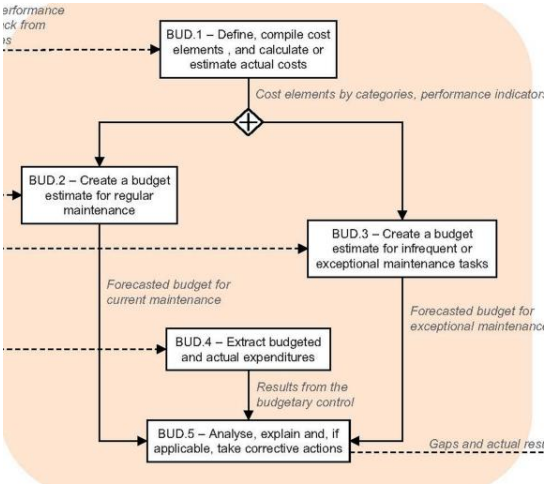

Figure 12 BUD process (BSI, 2017)

Delivery of the operational documentation

The process described and ensured that all documents are provided to those concerned. These documents need to be up-to-date and usable. The processes that are involved in this process are provided below and can be seen in Figure 13.

DOC.1 Define and manage rights to the documentation
Based on the organization in place, the people involved will be assigned to create and/or update and/or have consultation rights for each of the documents they need to perform the required actions.

DOC.2 Classify and structure the documentation
The documents should be classified by type and structured according to this use. This ensures that it can be easily found and that it is easier for maintenance providers to use.

DOC.3 Compile (collect, create) the reference documentation:
The documents need to be updated using the input of other processes. The document needs to be updated to new processes or standards. Item-related records need to be implemented (new drawings or procedures). Maintenance procedures need to be documented (operating rules). The documents needed to protect the health, safety, and the environment.

DOC.4 Update the reference documentation
The quality of a document, regardless of its nature, is directly linked to the updates made to the reference documentation when an editorial revision or substantive change is made to the subject matter of the document. These updates shall be made in real time, or within a required time period, by the individuals authorized to do so.

DOC.5 Ensure access to necessary information at all times
Regardless of the media used, the information contained in a document shall remain accessible to users at all times. Reference documents shall be backed up during the entire useful life of the document, taking into account changes to the documentation methods used.

DOC.6 Manage how operational documentation is made available
This entails specifying the organization, including procedures to be implemented, which allows the user to access the documents generated from the updated reference documentation that he/she needs promptly.

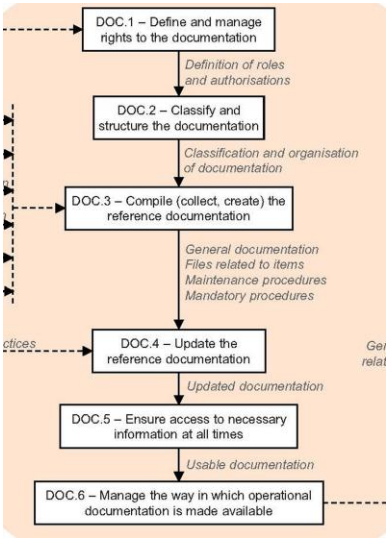

Figure 13 Documentation process (BSI, 2017)

Data management (DTA)
Collect, analyse, store, and transmit all data needed to document and improve the maintenance process. The process can be seen in Figure 14.

DTA.1 Store and validate the raw data in a library and/or a database
All the raw data internal to the process (corrective and preventive maintenance reports, item-related data, tools used, risk monitoring and management, time spent, costs, etc.) or external to the

maintenance process (production data) shall be validated and saved in an easy-to-use library and/or database. To be usable, this data shall be validated and classified according to its type and characteristics.

DTA.2 Evaluate the reliability and maintainability of the items by maintaining an actual state assessment of the items
Data regarding item failures and preventive and corrective maintenance actions are analysed periodically to compile indicators that show their reliability and maintainability levels. Indicators are often obtained using data about a family of similar items grouped, based on their technical, operating and environmental characteristics, either by hardware or by the functional system.

DTA.3 Draw up and maintain an up-to-date list of critical items
Critical items are items that lead to production losses, events that impact safety, security and the environment, costs, and decrease in the capital value of items.

DTA.4 Evaluate and analyse maintenance data and HSE data
Maintenance data (dates, durations, costs, tasks, etc.) and HSE data are analysed and compared to the expected values to calculate indicators that show the effectiveness of maintenance actions and Health-Safety-Environment preventive measures.

DTA.5 Evaluate and analyse data related to spare parts
Spare parts consumption, procurement times, stock levels, stock shortages, value, location, and all other pertinent data related to the supply of spare parts is evaluated and analysed. A distinction is made between the consumption of parts used for corrective and preventive maintenance.
DTA.6 Evaluate and analyse cases of known or predictable obsolescence
An obsolescence file is created. A distinction is made between cases of known obsolescence and predictable obsolescence, which are prioritised based on the severity of their consequences and the existence of applicable solutions.

DTA.7 Collect and analyse events at other organizations
Events at other organizations (internal and/or external) that may be associated with the items used (defects found, recurrent failures, improvements, etc.) are collected and analysed to ensure that appropriate actions can be taken to prevent the occurrence of similar events.

DTA.8 Compare maintenance practices and materials used by other operators or suppliers
By comparing the company's maintenance practices with those of other operators and/or with suppliers' recommendations, new economical and effective practices may be identified. Comparisons between uses of comparable items are also made to propose possible modifications or improvements.

DTA.9 Monitor methods, technologies, regulations, standards, etc.
Management methods, maintenance techniques, regulations and standards are continuously monitored to detect areas of improvement and/or to plan for updates to the company's practices and items.

DTA.10 Save and provide access to data in a data processing system
All data collected, validated, and analysed is saved in an information system so that it can be

accessed by the processes that use it.

DTA.11 Calculate, save and provide access to performance and monitoring indicators
Performance and monitoring indicators are calculated on request using the validated data available in the information system

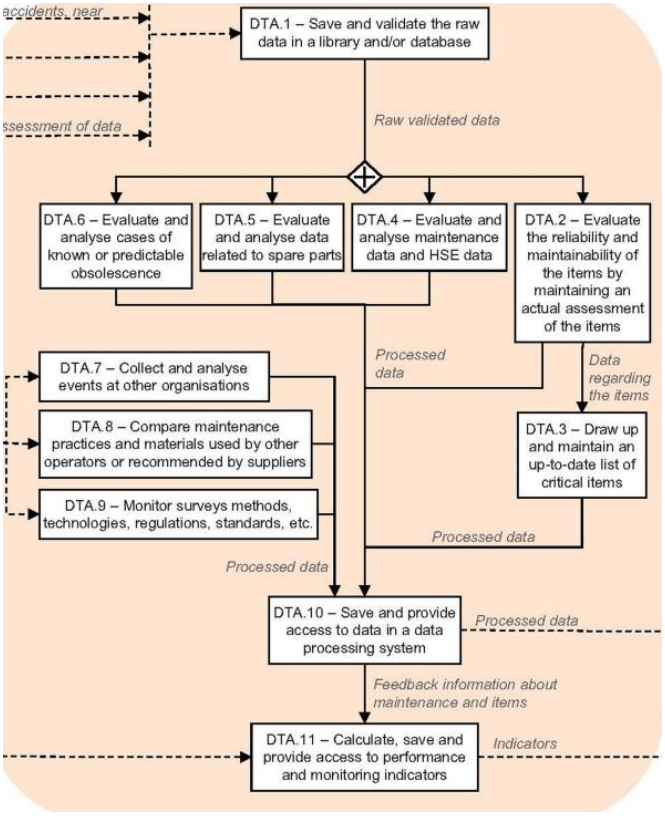

Figure 14 Data analysis process (BSI, 2017)

Infrastructure (IST)

Providing the infrastructures and facilities that all maintenance personnel need to fully perform their tasks in a manner that is safe for the individuals, the items, and the environment. The process can be seen in Figure 15.

IST.1 Plan and provide appropriate and safe premises and areas
The areas inside and outside the site needed for maintenance are identified, secured, and made available to the staff under the conditions required for the specified uses.

IST.2 Plan and provide the necessary power, utilities, and services
The power, utilities and services needed for the activities covered by the maintenance process are provided in the areas designated for the specified uses.

IST.3 Maintain and/or update the infrastructures and facilities
The infrastructures and facilities are maintained and updated regularly to ensure the safe completion of the activities covered by the maintenance process.

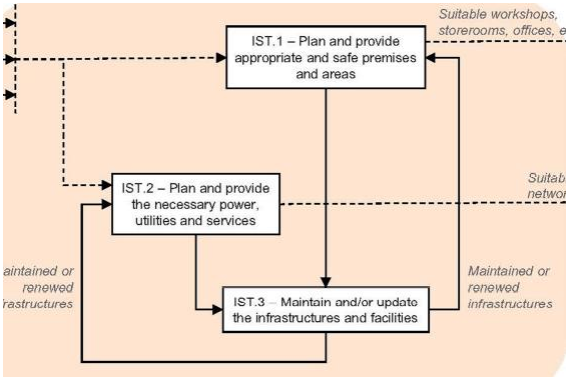

Figure 15 Infrastructure management (BSI, 2017)

Maintenance requirements (MRQ)

The purpose of this process is to define, monitor or realize and validate item investments, and modifications when the operational objectives are no longer reachable or have been changed. It defines the initial reliability, maintainability and maintenance support requirements, maintenance plans, the maintenance providers' related skills and the various logistical resources needed to implement the maintenance plan on these items.

MRQ.1 Collect feedback data

The feedback data needed to analyse item investments or modifications is collected so that it can be taken into account when specifications are drafted.

MRQ.2 Perform risk analyses

Risk analyses are performed according to dependability and safety criteria concerning planned investments and modifications. They include feedback data regarding accidents/incidents.

MRQ.3 Develop reliability, maintainability, and logistic support requirements

Evaluate and allocate reliability, maintainability, and logistic support requirements for item investments and modifications, so that they can be integrated into the specifications. These requirements could be obtained as an example through an analysis of the planned preventive and corrective maintenance actions.

MRQ.4 Oversee or contribute to the drafting of specifications

The previous requirements contribute to the drafting of specifications.

MRQ.5 Issue an invitation to tender to suppliers

Tender documents that include the specifications created by the company's various stakeholders are sent to the selected suppliers.

MRQ.6 Participate in the analysis and choice of options and validate the solutions

The responses to invitations to tender concerning item acquisitions, and modifications are analysed by
the company's stakeholders, particularly as regards aspects related to the maintenance process which may influence the choice of solution. The offers define reliability, maintainability and logistic support outcomes and are supplemented by a forecast analysis of the total cost of the life cycle of the items to be purchased.

MRQ.7 Follow-up realization

Item acquisitions and modifications are monitored to ensure that the reliability, maintainability and logistic support requirements are met without cost overruns and within the specified timeframes.

MRQ.8 Verify conformity with the reliability, maintainability, and logistic support requirements
The conformity of item acquisitions and modifications with the requirements indicated in the specifications are verified. This results in issuing a notice of conformity which facilitates the acceptance procedure.

MRQ.9 Establish the initial maintenance plan
The initial preventive maintenance plan related to the newly acquired, or modified items is established according to the reliability, maintainability and logistic support characteristics based on the supplier's recommendations and knowledge of the item's environment. The initial maintenance plan is recorded in the information system.

MRQ.10 Determine the initial logistical resources
The initial maintenance plan and the company's existing material resources determine the necessary initial logistical resources. The initial logistical resources are recorded in the information system.

MRQ.11 Identify skills and training needs
Skills and training needs are based on the initial maintenance plan and the skills in place at the company and those of its subcontractors.

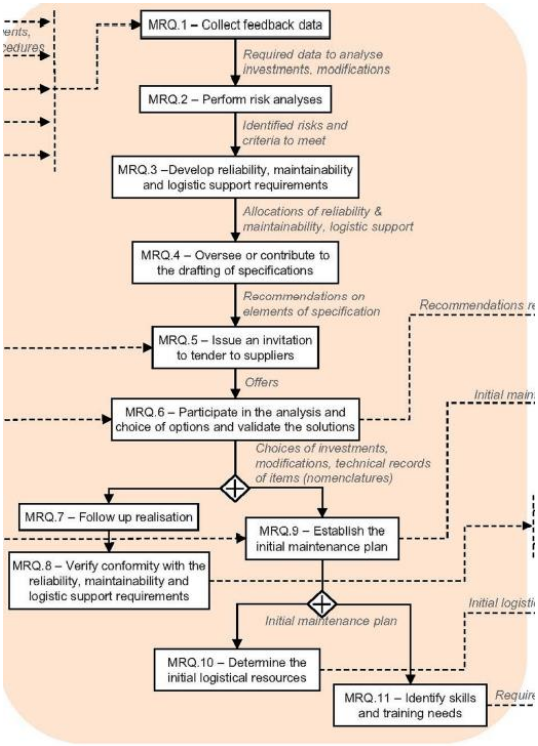

Figure 16 Management requirements process (BSI, 2017)

Optimisation (OPT)

This process represents a part of the continuous improvement loop which analyses the internal and external feedback data to determine actions to be taken, targets to be achieved and best practices to be applied for each of the processes. This process is used as input for the improvement process and is out of the scope of this research.

Resources (RES)

Provide promptly the internal human resources who have the necessary skill levels and certification to perform the maintenance activities.

RES.1 Manage jobs and skills

Based on needs and job profiles, determine future skills requirements, taking into account the indicators obtained through feedback.

RES.2 Recruit competent staff

Based on future skills requirements, foreseeable staff movements and the time it takes to make qualified staff available, recruit as necessary to satisfy needs in a timely manner.

RES.3 Ensure training, qualification, and certification of internal staff

Training allows the company's internal staff to update their knowledge and achieve higher qualification and certification levels. This process defines training objectives, develops, or identifies training programmes and then evaluates them. It provides the qualified internal staff needed to perform the tasks specified in the maintenance policy.

RES.4 Provide internal human resources

The competent internal individuals available to perform the maintenance activities are provided to the person who made the request.

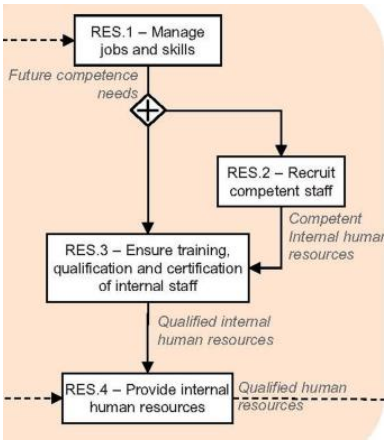

Figure 17 Human resources (BSI, 2017)

Services (SER)

Provide promptly the maintenance services carried out by external companies who have the necessary skill levels and certification to perform the maintenance activities.

SER.1 Identify competent external companies

This entails drawing up a list of companies that may carry out maintenance activities which management has chosen to assign to service providers. External companies are identified based on specifications related to the activities carried out. This list will be updated based on the evaluations made of past services (internal or external).

SER.2 Contract with external companies

Based on the need for maintenance activities defined by the user company, negotiate and enter into service contracts with previously selected external companies to perform the tasks covered by the contract. In particular, measures are taken to ensure that the service provider's staff has the necessary certification.

SER.3 Manage contracts and evaluate companies and services
Based on feedback indicators on the activities and opinions of the staff monitoring these activities, service providers are evaluated as part of the process of choosing and selecting companies. Every effort should be made to ensure compliance with all the provisions of the contract and, in particular, approval of the service.

SER.4 Provide external services
The external services which are available to perform the maintenance activities are provided to the applicant who made the request.

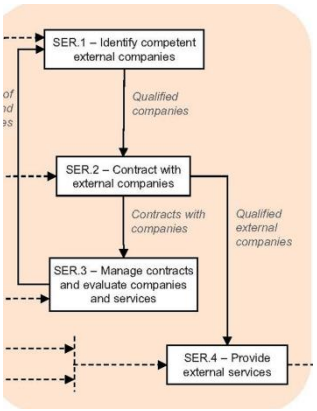

Figure 18 External services (BSI, 2017)

Spare Parts (SPP)

Provide the maintenance teams with the spare parts and, more generally, all spare items needed for the maintenance actions within the required timeframes.

SPP.1 Determine the spare items to keep in stock for maintenance
Based on suppliers' recommendations, initial logistics needs, experience, optimization of the references, objectives, and management activities, draw up a quantitative list of spare items to keep in stock. These spare items shall be properly identified and described.

SPP.2 Manage stocks
Stock management shall provide the ability to respond to spare item requests according to maintenance requirements and accounting principles of the organization. This management shall avoid excessively high stock levels and stock shortages that impact the time needed for items to be returned to service.

SPP.3 Reserve or issue a purchase request for spare items
Based on the lists of spare items to procure, draw up a purchase request. These lists are based on preventive and corrective maintenance needs. Just in time provisioning should be preferred for preventive maintenance, since spare items storage is planned to meet essentially the needs of unscheduled maintenance. They include the quantity in stock and procurement rules.

SPP.4 Order spare items from suppliers

Using the purchase requests the spare items are ordered from the selected suppliers based on the entity's management rules. It should be noted that, in some cases, reserving a spare item for a preventive maintenance task may be considered actual consumption and trigger an order process.

SPP.5 Establish and monitor contracts with suppliers
This entails entering into contracts with suppliers to determine the terms and conditions for supplying the spare items (price, price escalation clauses, contract reviews, partnership agreements, minimum purchase quantity, delivery times, penalties for breach of obligations, etc.).

SPP.6 Receive ordered or repaired spare items
Ensure that the spare items delivered conform to the order in terms of quantity and technical compliance.

SPP.7 Add the spare items to stock
This entails storing the spare items in a place designated for that purpose based on their specific characteristics or risks such as humidity, temperature, light, dust, etc. Expiry dates of spare items in stock should be taken into account, where applicable. The storage location may sometimes be close to the item on which maintenance is performed. Each spare item shall be identified (item code) and have a location (or storage area). Spare items are entered as stock in the accounting system and documentation and an inventory check are performed by the applicable regulations.

SPP.8 Perform preventive maintenance on spare items in stock
This entails checking that spare items are properly stored by performing regular inspections to ensure that the packaging is still adequate, by following certain procedures, and by checking the expiry dates of certain spare items.

SPP.9 Deliver spare items
Identify, remove, and deliver the requested spare items based on a materials request and make them available at the desired place. Ensure that there is no evidence of damage.

SPP.10: Assess replaced items
This process entails determining whether the item can be repaired at an acceptable cost.
For repaired items, expertise shall be done to judge the feasibility and relevance to repair them again.

SPP.11 Repair replaced items
Following an assessment, this process entails initiating the repair of the replaced items.
The repaired item shall be identified as such since it will not necessarily have the same level of reliability as a new equivalent spare item.

SPP.12 Disposal of faulty or damaged items
Following assessments of replaced items, this process entails scrapping replaced items and taking care of relevant safety and environmental regulations and the specific characteristics of the item.

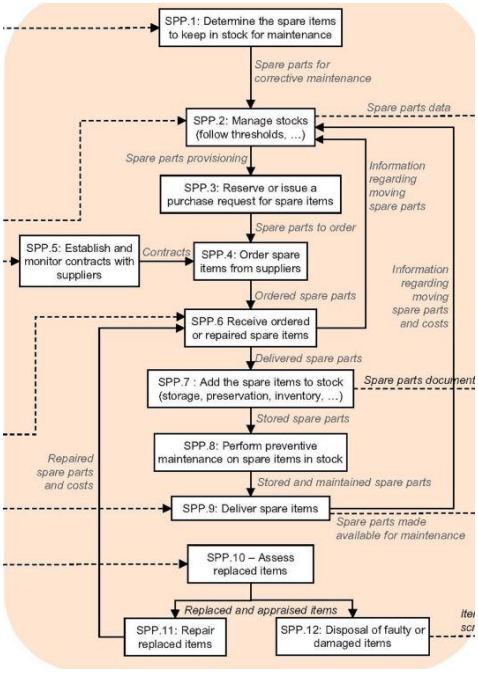

Figure 19 Spare parts management (BSI, 2017)

Tools (TOL)

Provide users with the operational technical resources needed for maintenance.

TOL 1 Determine and provide the support equipment needed for maintenance

The support equipment needed for maintenance includes conventional and specialized tools, tests, monitoring and control equipment etc. It is identified and the solutions for providing access to it under the best possible conditions are chosen based, in particular, on costs and timeframes.

TOL.2 Store the support tools and equipment

Support tools and equipment are stored under appropriate environmental conditions in clearly marked areas are chosen according to usage constraints.

TOL.3 Maintain and/or update the support equipment

As a preventive measure, support equipment is maintained based on a fixed schedule and repaired or replaced in case of failure. It is updated when necessary.

TOL.4 Deliver the tools and other support equipment

The support tools and equipment are made available to maintenance staff in a timely manner, at a specified place and under the required conditions of use.

TOL.5 Determine and provide maintenance management, decision support software tools and documentation system. The maintenance and documentation management system and decision support software tools are designed or acquired based on the company's needs.

TOL.6 "Maintain" and/or update the maintenance documentation system

The maintenance and documentation management system and decision support software tools are Maintained and updated, as necessary. Its availability is ensured and the information is backed up regularly and kept safe.

Many companies today consistently purchase equipment based on the low bid quite simply if they are not performing the task listed for the Maintenance Foreman and Maintenance Planner the company lacks the data to purchase equipment based on the life cycle philosophy without the data the purchasing accounting department will purchase the lowest cost items which may or may not be the best long term decision this collecting maintenance cost data is important many companies today consistently purchase equipment based on the low bid quite simply

3.3 Conclusion

The process steps that will be included in the maintenance model will be all the subprocesses and the preventive and corrective maintenance processes. These processes form the core of the total maintenance process and can be made general. This is needed because the paper is not addressing a real company where improvements are made. The management process will be included but only in an overview. This is needed to make clear that the strategy and policy of the management are implemented in all processes. Therefore, this could not be excluded. The improvement process of maintenance items will be excluded because this process can be seen as a separate process in the maintenance processes. It is needed to make the whole maintenance process optimal or fully mature, but with the assumption made that the improvement process is included in the maintenance processes of the whole company we can still make an optimal maintenance model. The improvement of machines is still needed inside companies.

The tasks mentioned in the processes will be included in the maintenance model to comply with the EN-17007. But to make the process easier to adapt, the personnel who are responsible for the tasks will be added. Also, the tasks that are needed to comply with tasks of the EN-17007 will be added. This will be the case in the preventive and corrective maintenance and the acting of the maintenance tasks.

4 Business process modelling

In chapter 4 the found processes in chapter 3 are translated into the business process modelling language chosen in chapter 2. While standard processes as described in the previous chapter are important, in the search for the optimal case, it is even more relevant particular experiences and realistic situations are taken into account in the analysis. This is to make it useful for the consultancy company and show it to the customer to make clear what is meant with an optimal case. In this chapter, the model is evaluated by maintenance experts and tested for maturity with the help of the maturity models mentioned in chapter 2. The questions that will be answered in this chapter are questions 3 and 4.

Questions 3 and 4

1. *How would an optimized to-be maintenance business process model compliant with EN-17007 look like?*
2. *How is the optimized to-be maintenance business process model evaluated?*

4.1 Method

Before we look into the models themselves, it is important to make explicit the method used for their development. First of all, a draft of the optimal maintenance structure is made. This is done according to the EN-17007 standard. The first draft is conducted according to the processes from EN-17007 and made more specific with the use of the input of Terry Wireman (Wireman, 1998). With the use of this, the maintenance process has been made more specific and the input and output variables in each stage are represented. The business process models are made according to the BPMN 2.0 language as discussed in chapter 2.

After the first draft according to the EN-17007, an unstructured interview with two maintenance experts is held to make the model more realistic. This is used to make the more specific. The maintenance experts are both working at Catch 22 as maintenance consultants and are experienced in the field of maintenance processes. The maintenance processes are also checked by looking at fields that are expected to have mature maintenance processes. The oil and gas industry are an example of an industry to have very good maintenance processes according to the experts of Catch 22.

The model is evaluated according to the maintenance maturity models as mentioned in chapter 2. The maintenance model is improved and adapted to fit the highest maintenance maturity and therefore can be seen as optimal.

The description of the processes in the research is done by first addressing the process and explaining this. In the communication with other processes the link between the processes is explained and the documents/tools that are used in the process or produced are mentioned.

4.2 Results

The total maintenance process

Following the EN-17007 structure, the whole process will be split into different sub-processes and thus explained in different sections. Therefore, the process is divided into the manage maintenance process, preventive and corrective maintenance, performing the maintenance tasks and the different supportive processes. The supportive processes will not be analysed in detail, because this will take too much time for this research. The detail of the supportive processes can be done in further

research. The supportive processes are different for each company and therefore a general detailed view will not be of use. Therefore, the supportive processes are just covered in general.

First, a collaboration diagram is made, this is a high-level overview without specific tasks of the maintenance process. The connection between all the subprocesses, which are addressed in the following Figure 20. The diagram shows the starting points of different maintenance tasks, corrective and preventive maintenance. It also shows the performed subprocesses by different personnel. As can be seen, the interconnectivity between all processes is needed to be a mature maintenance process (Oliveira et al., 2019; Tortora et al., 2022).

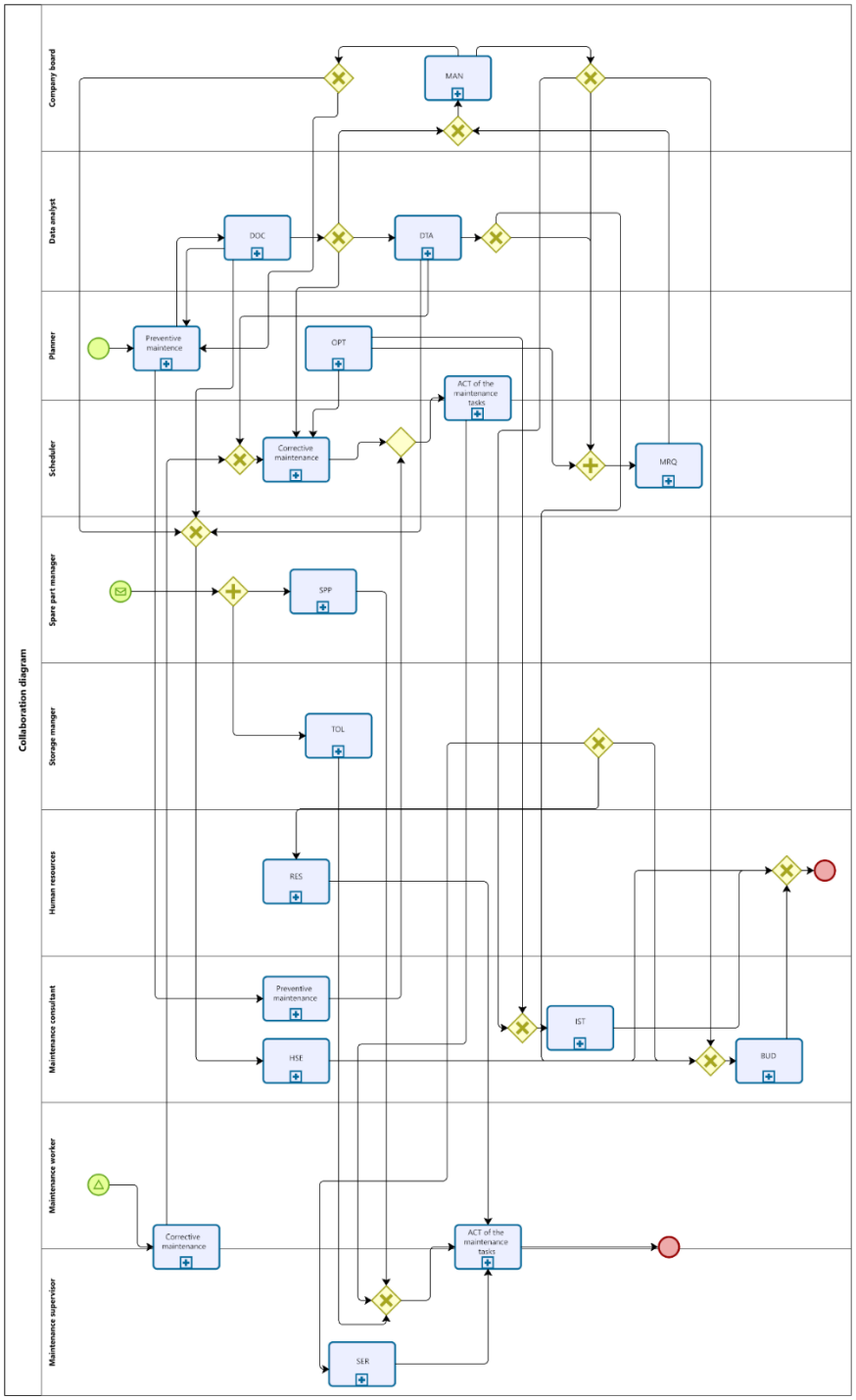

Figure 20 Collaboration Diagram

Manage maintenance process

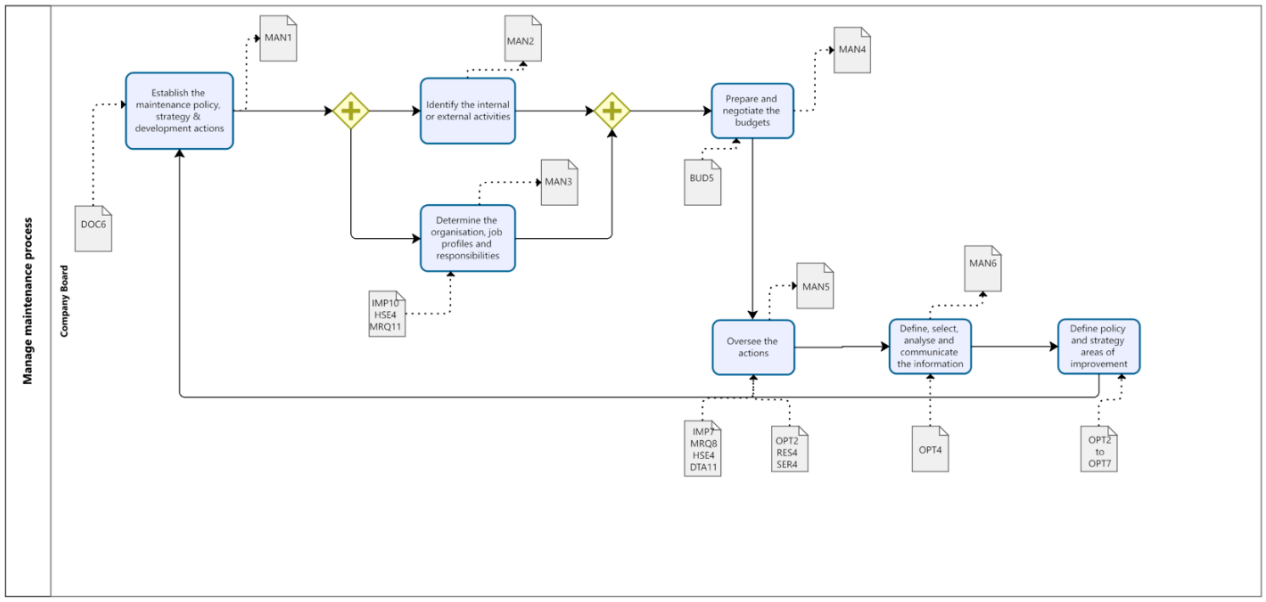

Figure 21 Manage maintenance process

The manage maintenance process is a series of steps that the board of directors of the company follows to guide subprocesses. This process begins with establishing the maintenance policy, strategy, and development of actions, and it includes input from the subprocess documentation (Docherty et al., 2014). At the end of this task, a document is produced outlining the maintenance that was performed (MAN1). The process may also involve adjusting the strategies or policy, resulting in a new strategy and guidelines document (MAN1).

The manage maintenance process then consists of two parallel activities: identifying internal or external activities and determining the organization, job profiles, and responsibilities. After these tasks are completed, the budget is negotiated and prepared, using input from the budget subprocess (BUD). The next step in the process is overseeing the actions that flow from the subprocesses, using seven documents from various subprocesses, such as the spare parts subprocess, to perform maintenance tasks. These documents are combined into two documents for a clearer overview of the model.

The final activity in the process is defining, selecting, analyzing, and communicating information, with the output being a document shared with all parties involved in the maintenance job. The process then loops back to refine the policy, strategy, and areas of improvement, evaluating the maintenance tasks and adjusting the outcomes in terms of strategy and policy. This loop is determined for each company and may repeat annually, semi-annually, or monthly, depending on the company's overall strategy.

Communication with other processes.

The communication and transfers between other processes is shown as documents. In the manage maintenance process, a lot of strategy documents are made which are used in other processes. The needed document for this process is DOC6, which is a document produced by the documentation process and describes how documents should look like. The document HSE4 is a document on the possible risk to health and safety inside the company. MRQ11 is a document about the skills and

training needed for the staff. IMP10 is a document about the possible improvements in the company, this is made in the improvement subprocess. In the next task, the BUD5 document is used for making a decision, this is a document made where analysis is done on the expenses of the company on the different assets. For overseeing the actions, reports of the different subprocesses are needed, from data, the DTA11, which describes the performance on different indicators. The RES4 is about the personnel of the company. Then OPT2 is about the optimization of assets in the preventive and corrective maintenance areas. Again, the HSE4, the MRQ6 which validates the decisions and then finally the SER4 which is about the external services provided in the company. In the next two tasks, OPT2 to OPT7 are used to determine the improvement areas. All these documents provide insights into different subprocesses and their possible improvements.

Preventive maintenance

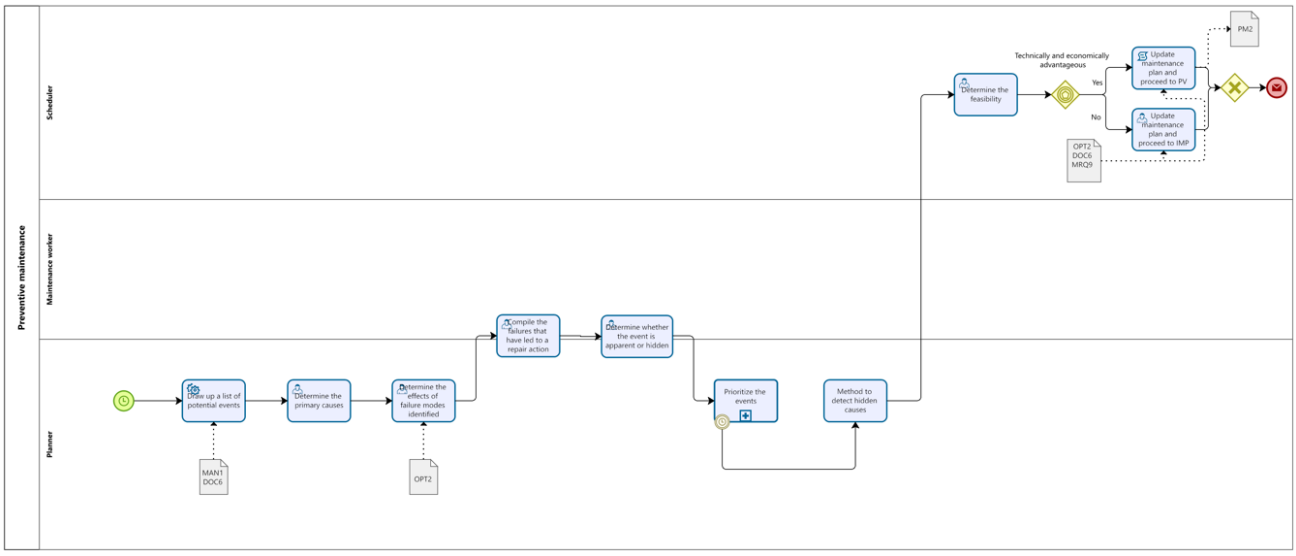

Figure 22 Preventive maintenance

The preventive maintenance, Figure 22, is a time-based event process, this is done each month, every 6 months or yearly. This depends on the strategy of the company. The first process is to **make a list of potential events**. These events, i.e., potential failures, are determined by the strategy and the documentation of the maintenance already performed by the Maintenance Workers. After this list is made for each event, the **primary causes are determined.** For each **event, the effects of failure are determined.** The upgrades of the companies' assets are used as input. Next, **the failure that could lead to a repair action is determined.** After this, there should be looked at **whether the event is hidden or visible** or in other words, whether the failure could be detected or not. In that way, one may determine if the failure is going to happen in the near future. For most assets, a p-f curve, Figure 23, is used to detect the failure when it is hidden.

A p-f curve is used to see the potential failure of an asset according to time. In this curve, f is the functional failure. Therefore, when the failure is hidden these types of time-based curves should be used for determining when to perform preventive maintenance. The maintenance should be performed between potential failure (P) and functional failure (f). It is best to divide the p-f curve further into sections between P and f. This can be useful to determine possible cost savings with smaller maintenance jobs (Van Horenbeek et al., 2013).

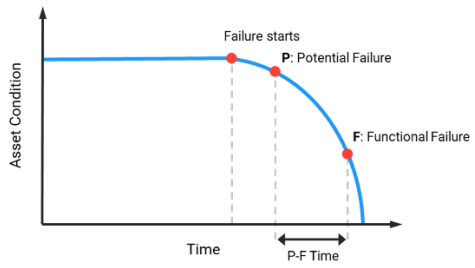

Figure 23 P-f curve

It Is important to perform preventive maintenance because this lowers the total cost of the maintenance. In Figure 24 Maintenance cost graph can be seen, showing that the total cost is lowest when predictive maintenance is performed. This is the case when having clear documentation on when to perform maintenance tasks.

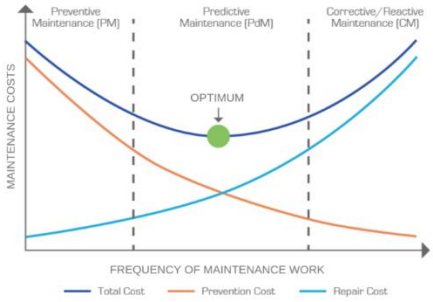

Figure 24 Maintenance cost graph (Wu, 2021)

After this, **the events should be prioritised**. This is made using a risk matrix, an example can be seen in Figure 25. Note that the prioritisation of preventive work is not precisely calculated, but the risk level is defined to make up a priority list. The precise priority calculation is more important for corrective maintenance. In the risk assessment matrix, there is an axe of severity and an axe of probability. For the assets, in the production facility, a risk assessment should be made. This is a standard subprocess in the preventive maintenance process. It evaluates and selects assets which have safety, operational and significant economic consequences of functional failure (Cui et al., 2011).

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Figure 25 Risk assessment matrix

Following this prioritisation, there should be made a **method to detect hidden causes** when this is not present. This is the case when no p-f curve is present. In that case a run time could be set when to check the assets, this depends on the strategy and policy of the company. Next, **the feasibility of**

the maintenance should be determined. This is determined according to the budgeting and previous maintenance performed. After this, there is a gateway where it is either planned for preventive maintenance or the process of asset improvement is started. The list of preventive maintenance assets is used in the acting of the maintenance tasks, which can be found in Figure 28.

Communication with other processes

In the first task of the preventive maintenance process, a document of the MAN1 is used to comply with the strategy addressed by the company board. Also, DOC6 is used which describes the way documentation is accomplished at the company. For that, OPT2 is used to determine if preventive maintenance is still needed. When making the maintenance plan, DOC6 and OPT2 are used again. This task also uses the MRQ9, which provide predetermined maintenance plans for assets in the company.

Corrective maintenance

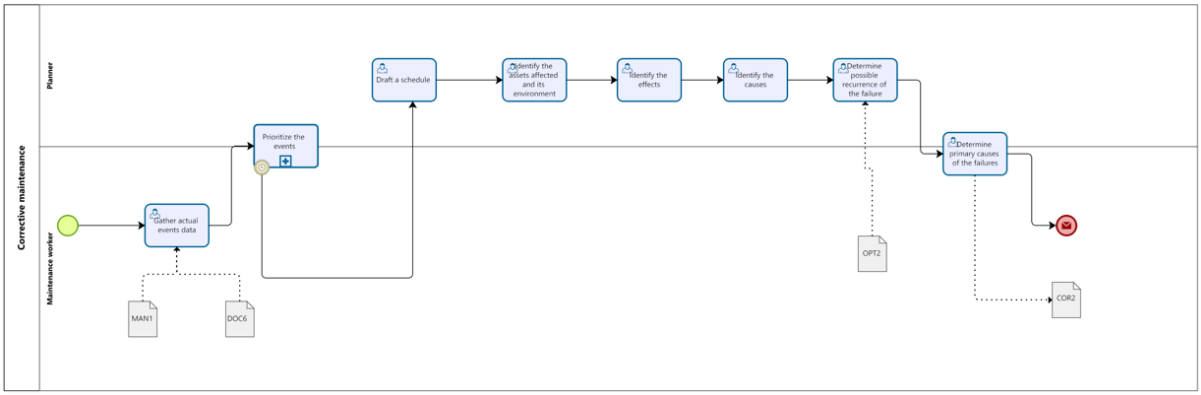

Figure 26 Corrective maintenance process

The corrective maintenance process starts when an event takes place (see Figure 26). An example is that an asset has failed to perform in the correct way. The first process is to **gather actual event data.** This data is collected from the subprocesses which include this particular, besides the manufacturer or engineer. When this data is collected, all the corrective maintenance tasks are prioritised. This is done according to the subprocess ***prioritize work events***. This is a subprocess that will start so that the Planner can prioritize the work events in the planning.

Communication with other processes

This task uses MAN1 and DOC6 since the beginning. These documents provide the maintenance strategy and the documentation approach. Then for the recurrence of the failure, OPT2 is used to optimize the assets.

Prioritize work events

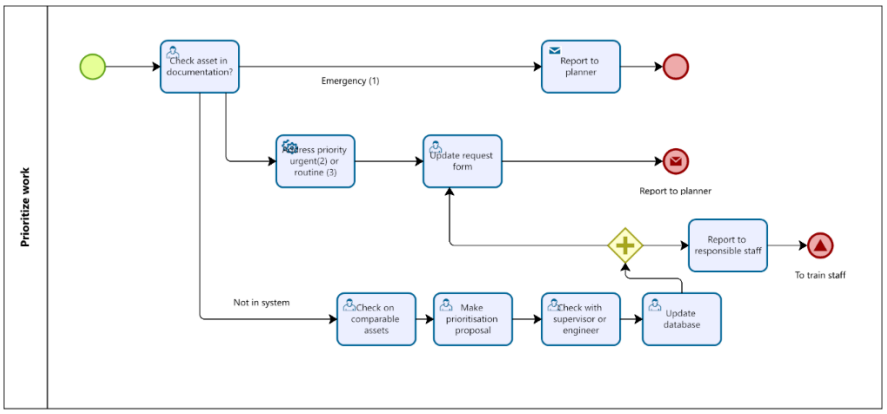

Figure 27 Prioritize work subprocess

The event starts and is almost automatically finished when the event is known. In this subprocess (see Figure 27) the maintenance task is given a value of emergency (if it requires immediate action), urgent (if it can be planned but has to be done in the same week) or routine (if it can be planned and executed when possible) (Wireman, 1998). For most assets, this is predetermined. But when this is not the case, a prioritisation should be made according to the steps mentioned in the process. This is done by **checking comparable assets**, **making a prioritization proposal**, and then **confirming it with the supervisor**. Last but not least, the **database is updated** with the prioritization information.

After the prioritisation, a first **schedule is drafted.** The **effect on its environment is determined** and next, the **other effects are determined.** Following, **the causes of the failure are identified** and after that, the **possibility of recurrence is determined**. Finally, t**he primary cause is concluded** and the draft is sent to the ACT of PV and COR (Wireman, 1998). This is where the processes of preventive and corrective follow the same procedure and is a combined process. In other words, from this point on, the actual maintenance task is performed.

Perform the maintenance tasks

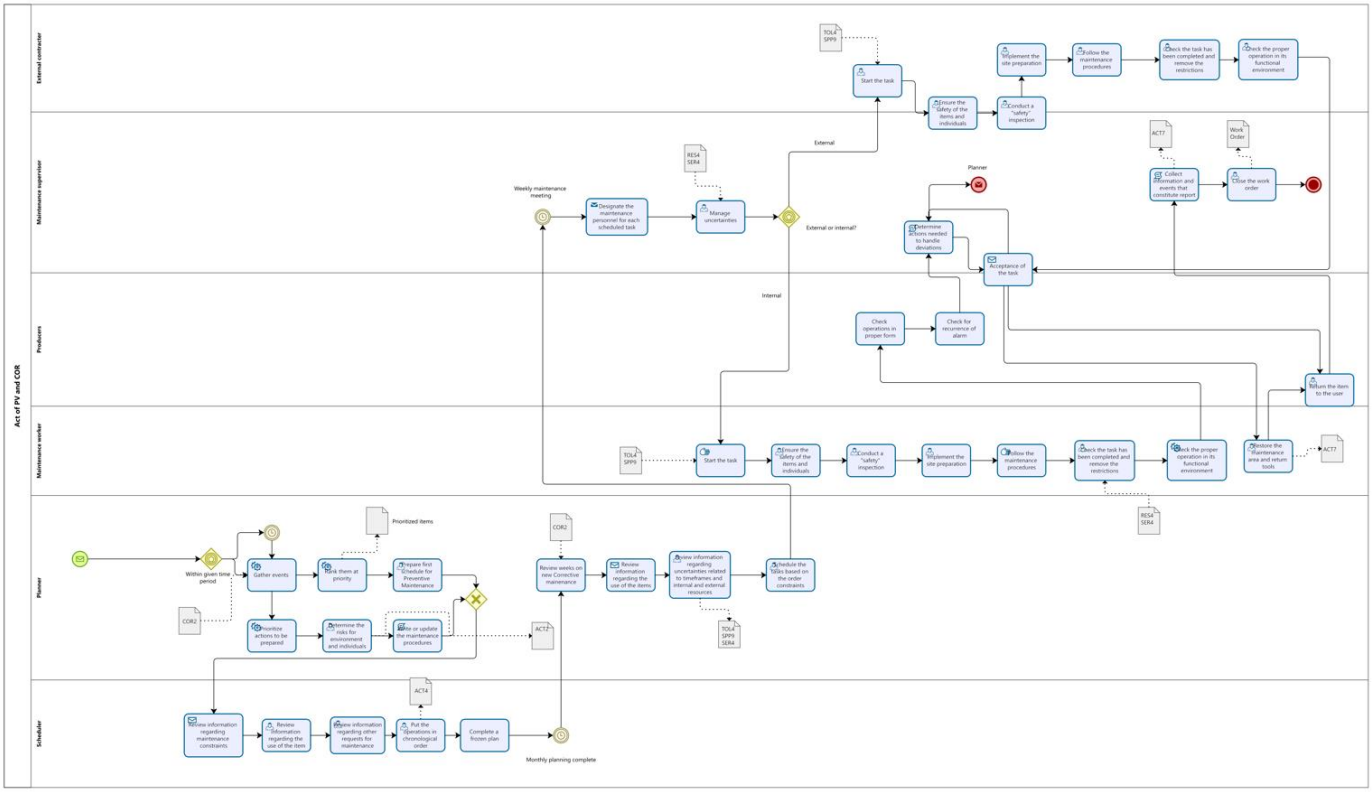

Figure 28 Acting of the maintenance tasks

The maintenance tasks (see Figure 28) first starts at the Planner in the company. Some tasks are combined and performed by one person. This is for an average company where all the processes are performed by different persons. The schedule of the preventive and corrective maintenance is collected at **gather events** activity**.** Some events are based on either certain activities that happen, or they are event-based, or time-based. This is mainly for the preventive maintenance tasks. After collecting all maintenance tasks, another ranking should be done to prioritize the events correctly. The first **schedule is made.** At the same time, **the actions are prioritized** and **the risks of the performed tasks are determined**. Next, the **maintenance procedures are updated accordingly**.

The first schedule of the Planner is sent to the Scheduler, which will first **review information according to the maintenance constraints**. This is needed to make sure that the tasks can be performed. Also, the use of the asset is reviewed along with other maintenance task requests. This is reviewed looking at personnel and materials (i.e., organizational resources). Then, **the tasks are put in chronological order** for the week and a first **frozen plan is made**. This plan is called frozen because now no changes can be made to the schedule. Only corrective maintenance tasks with urgent priority can change this.

The frozen plan is then adjusted by the Planner when new corrective maintenance tasks come up. Again, the Planner reviews **the items**, **the timeframes** and **the use of external or internal resources**. Then a final **schedule is made for the week, according to the maintenance constraints**.

The Maintenance Supervisor **assigns Maintenance Personnel to each task every week**. Moreover, the Maintenance Supervisor **manages uncertainties**, meaning that she is also accountable for uncertainties, eventually correcting these uncertainties or changing course when needed. This is also based on the subprocess input of the resources available at that moment (Figure 35). There is then a difference when the task is performed internally or externally, in terms of responsibilities.

Internal Maintenance

The Maintenance Worker begins the tasks by gathering the necessary tools (TOL) and spare parts (SPP). They ensure the safety of the items and personnel before conducting a safety inspection and preparing the site. The Maintenance Worker may lock out the entire production or only the specific asset. Following the maintenance, the task is performed, and the item is checked for correct installation and any restrictions are removed. The asset is then tested by the Maintenance Worker. The Producer also tests the asset by sing it in a normal manner and checking for any recurring alarms or failures. Any deviations are reported to the Maintenance Supervisor, and the task is accepted. The final step is that the Maintenance Worker cleans up the site, returning the tools and returning the asset to the user.

External Maintenance

The external process starts in the same way as the internal process only now the external company is **starting the maintenance task.** The difference is the responsibilities in clearing the site and conducting a safety inspection. This is done together with the Maintenance Supervisor because that is the responsible person on the floor. **The asset is checked in production** and then acknowledged accordingly with the Production Worker and the Maintenance Supervisor. After this, the maintenance task is completed and the external company can leave the facility again.

After the maintenance is performed data is collected from the maintenance and documented. The Maintenance Supervisor documents the data in the work order and the work order is closed. This is the end of performing the maintenance task.

Communication with other processes

First of all, COR2 is used which is a document about the corrective maintenance tasks to be performed. These are corrective maintenance tasks that do not have emergency priority. CM2 is a document about the emergency maintenance tasks and this is used later in the process to make sure that the tasks are performed fast. For managing the uncertainties, the Manager Supervisor uses SER4 and HSE4, which are about safety and health, and also about the external services that will perform maintenance tasks. Finally, the Maintenance Worker uses SPP9 and TOL4, which regard the spare parts needed for the tasks and the tools, respectively. This is represented as a document but in real life, these are actually objects. The usage, of these last two resources, is in the activities done both by the Maintenance Worker and the External Worker.

Supportive processes

The supportive processes are there so that the maintenance tasks can be performed correctly. Each of these processes may be differently done, but they are equally important to achieve the optimal maintenance process according to the EN-17007.

Health and Safety (Karimi et al., 2020)

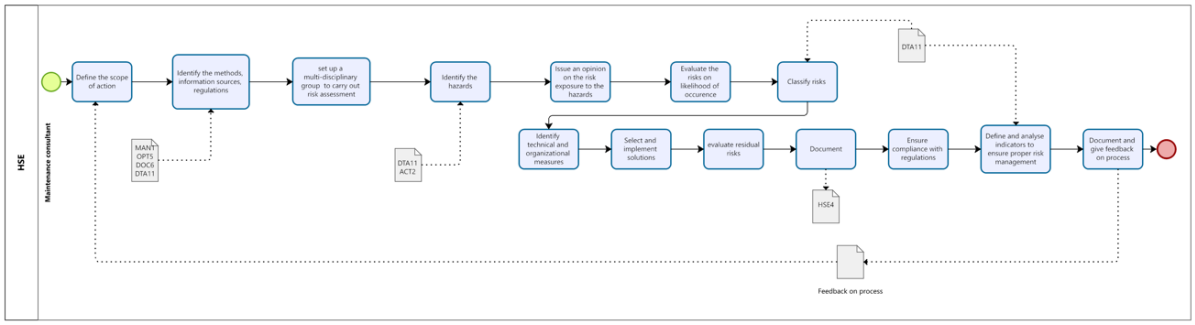

Figure 29 Health and Safety process

The health and safety within the company should be performed according to the process depicted in Figure 29. What is noticeable is that this is mainly based on processing data and creating important documents on how to deal with hazards or health issues. That is an important factor to improve the health and safety risks. The outcome of this subprocess is used in the performance of the maintenance tasks and the determination of the strategy and policy of the company regarding maintenance.

Communication with other processes

MAN1 and DOC6 are about the strategy of the company and the company's documentation approach. DTA11 is about the performances of the different indicators. OPT5 is about the possible improvements in the subprocesses. Next to identifying the hazards, a document from the acting of the maintenance tasks, ACT2, is provided. Also, again DTA11 is used to determine the hazards. For classifying the risk and making an analysis, DTA11 is used again.

Budgeting (BUD)

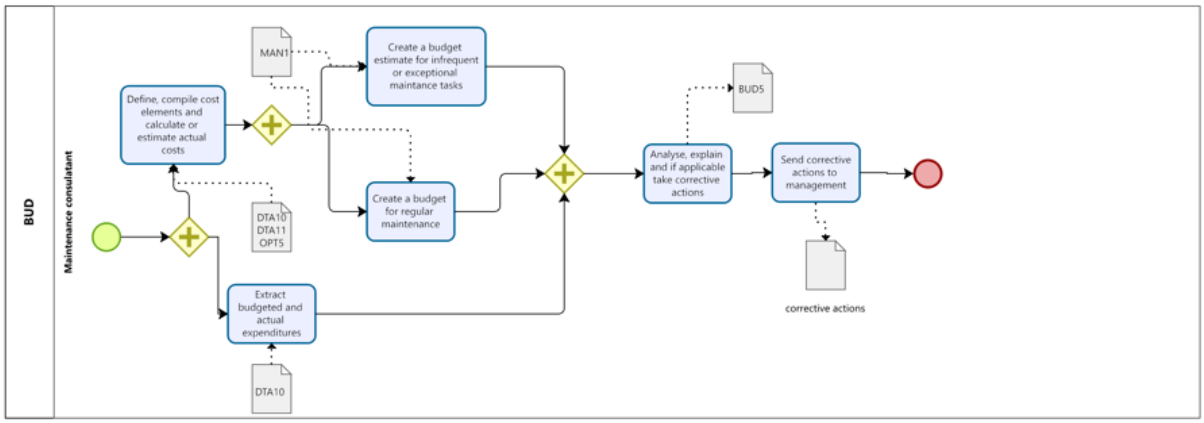

Figure 30 Budget maintenance process

The subprocess for the determination of the budgets is depicted in Figure 30. In this subprocess, the strategy and policy determined by the company is used to create budgets for the maintenance tasks. The focus point is the use of data where the budget could be evaluated and adjusted when necessary.

Communication with other processes

In the first tasks, DTA10 and DTA11 are used to determine the budgets of different assets. These documents provide insight in the performance and access to the data. OPT5 is about the

optimization of the subprocesses. When actually estimating a budget, MAN1 is used to comply with the maintenance strategy. DTA10 is again used to determine the actual spent budget.

Documentation (Docherty et al., 2014)

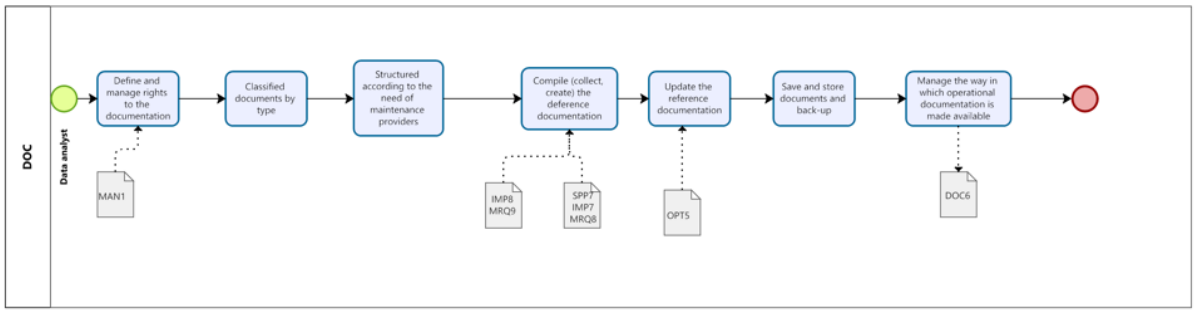

Figure 31 Documentation process

The subprocess documentation is about how the structure of documentation should be caried out (see Figure 31 Documentation process. This is needed to guarantee that documents are similar, without being concerned about who performed the maintenance task or research. This is based on the strategy and policy of the company and the performed maintenance tasks. The output of this process is a document used in the management process of the company and the performing of the maintenance job.

Communication with other processes

MAN1 is used to follow the strategy provided by the management board. IMP8, MRQ9, SPP7, IMP7 and MRQ8 are all documents produced in the subprocess and checked on consistency and correctness. OPT5 is used for checking whether improvements are needed in the subprocesses.

Data (DTA)

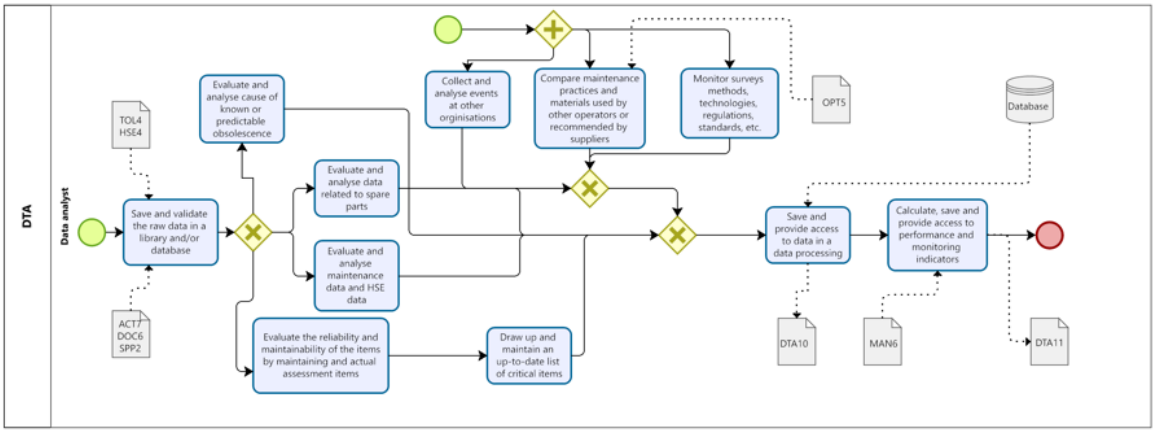

Figure 32 Data management process

The other subprocess is data management, as depicted in Figure 32. As said earlier this is a very important process. The input of raw data from other subprocesses is used as input and then evaluated and analysed. The analyses of the data depend on the input given. Another important input is information from other companies about the same assets or the manufacturer of the assets. Eventually, the data is stored correctly and used as input in other subprocesses and main processes.

Communication with other processes

The data is collected from the following subprocesses and processed. From Tools, Health, and Safety, Acting of the maintenance tasks, documentation, and spare parts. This is represented in the documents TOL4, HSE4, ACT7, DOC6 and SPP2. OPT5 is used to improve the subprocess DTA. Finally, the MAN6 is used to follow the communication structure determined by the company board.

Infrastructure (IST)

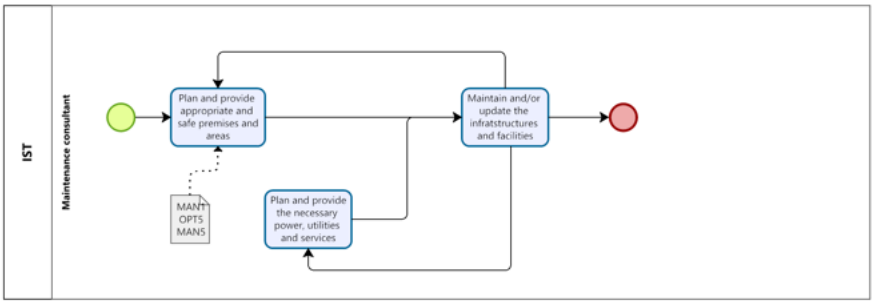

Figure 33 Provide of infrastructure process

The infrastructure subprocess is a continuous process to update the infrastructure inside the company, as depicted in Figure 33. This is needed to keep working in a good manner.

Communication with other processes

MAN1 is used to follow the strategy provided by the management board and MAN5 is used for complying with the management board when they oversee the actions of the other sub-processes. Finally, OPT5 is used to improve the sub-process.

Maintenance requirements (MRQ)

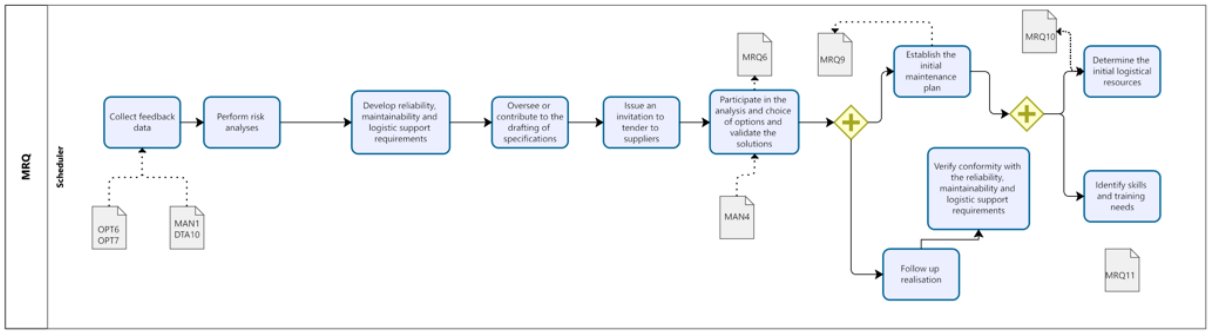

Figure 34 Maintenance requirements process

Maintenance analyses are needed to perform good and efficient maintenance tasks, according to the process in Figure 34. The maintenance tasks that are performed are analysed and evaluated. Adjustment to the maintenance plan is initiated or maintenance personnel are trained to keep performing the maintenance tasks.

Communication with other processes

MAN1 is used to follow the strategy provided by the company board. OPT6 and OPT7 are respectively documents about improvement on current assets or for future investments. DTA10 is the access to the data collected by all the other processes. The connection when deciding on improvements or solutions is MAN4. This is a document in need of validation by this subprocess.

Human resources (RES)

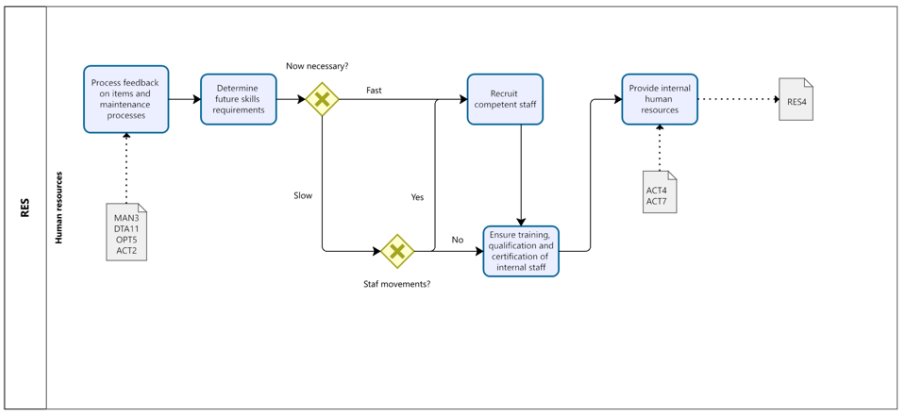

Figure 35 Human Resources process

The resources of the company are mostly about the personnel at the company. It is about hiring new maintenance personnel and training these new employees correctly. This needs to be structured to guarantee the same level of expertise, as depicted in Figure 35.

Communication with other processes

For the feedback on maintenance processes, documents are collected from DTA11 and ACT2 these are used to determine the appropriate staff. Also, the strategy on jobs from the company board, MAN3, is used. OPT5 is the optimization of the subprocesses and is used to determine appropriate staff. Finally, ACT4 and ACT7 are the feedback and needed personnel for the performance of the maintenance tasks and RES then provide the personnel needed for the tasks.

Improvement process (OPT)

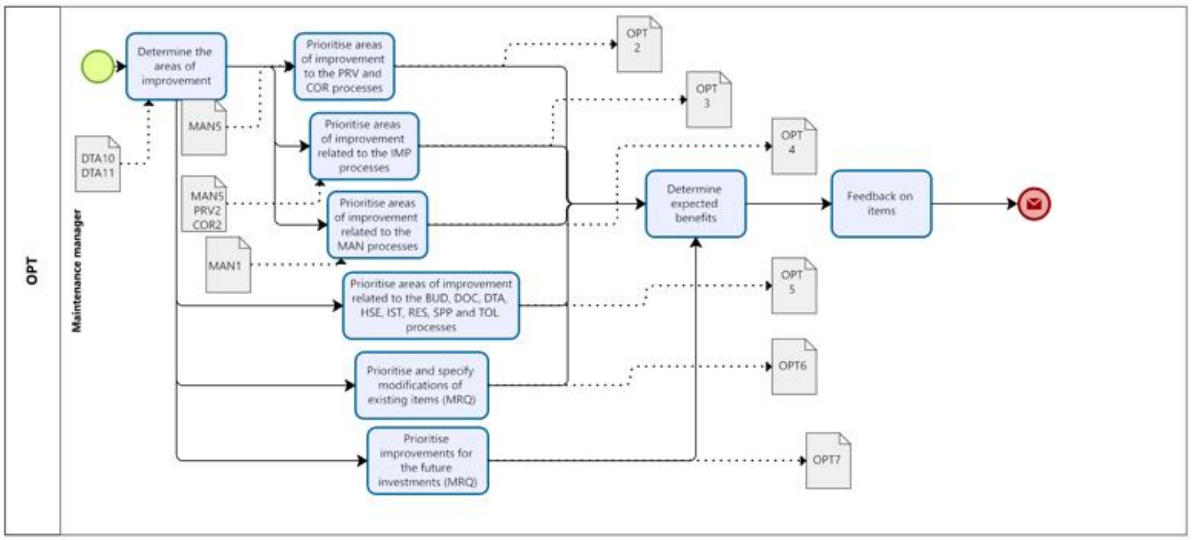

Figure 36 Improvement process

The subprocess improvement, as displayed in Figure 36, is about replacing the assets in the company. This is needed in a company but out of the scope of this research. The process is also about improvement in the company a feedback loop. These are necessary for improving the processes and

company to the next standards and needs. The improvement of processes is needed to be a fully mature maintenance process (Oliveira et al., 2019; Tortora et al., 2022).

Communication with other processes

The data on the assets and from all the other processes are collected by the DTA10 and DTA11. The company boards provide actions needed in the company by MAN5. PRV2 and COR2 are documents on possible needed improvements that should be looked into. MAN1 is the strategy of the company board and is used to improve the management process. This process provides input for all other processes to improve them.

Tools (TOL)

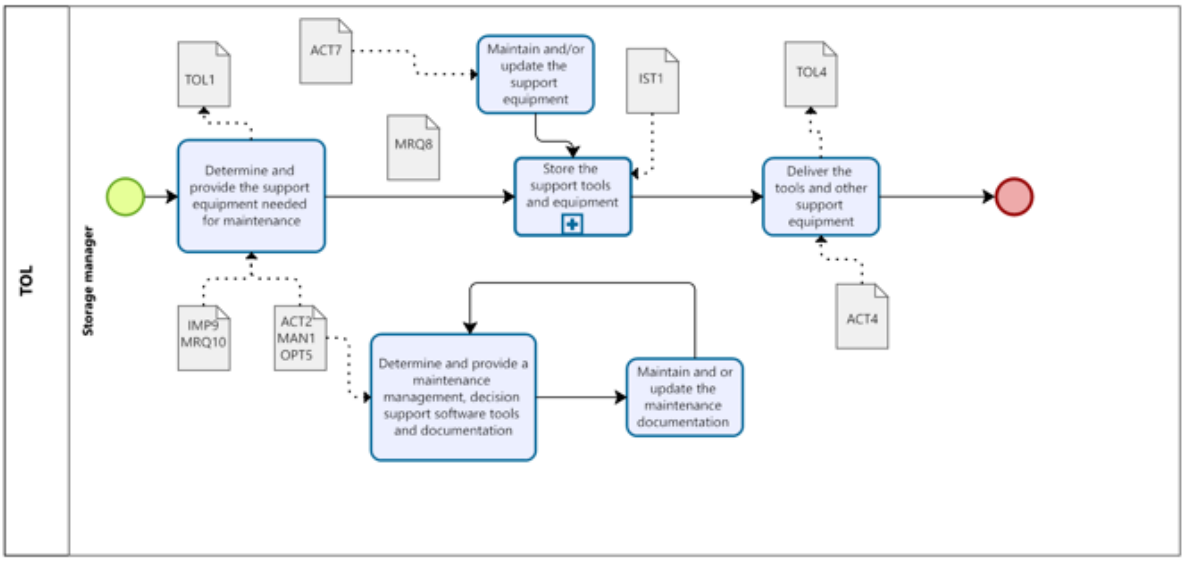

Figure 37 Delivering of the tools process

The tools needed for performing the maintenance tasks are collected and put away according to the TOL subprocess, depicted in Figure 37. In this process, it is also needed to perform maintenance on the tools to keep them up to date. The subprocess of the storage of the tools can be looked further into but was not the scope of the project.

Communication with other processes

ACT2 is the request of the tools needed for the maintenance task to be performed by the Planner. MAN1 is needed in order to follow the strategy of the company board. The documents for improvement and updates on the assets are needed in order to still know which tool is needed for which asset, shown as IMP9 and MRQ10. OPT5 is needed to improve the subprocess. ACT7 is the return of the tools and then they can be checked by the storage manager. The ACT4 is the actual collection or delivery of the tools to the Maintenance Worker or external services.

Spare parts (SPP)

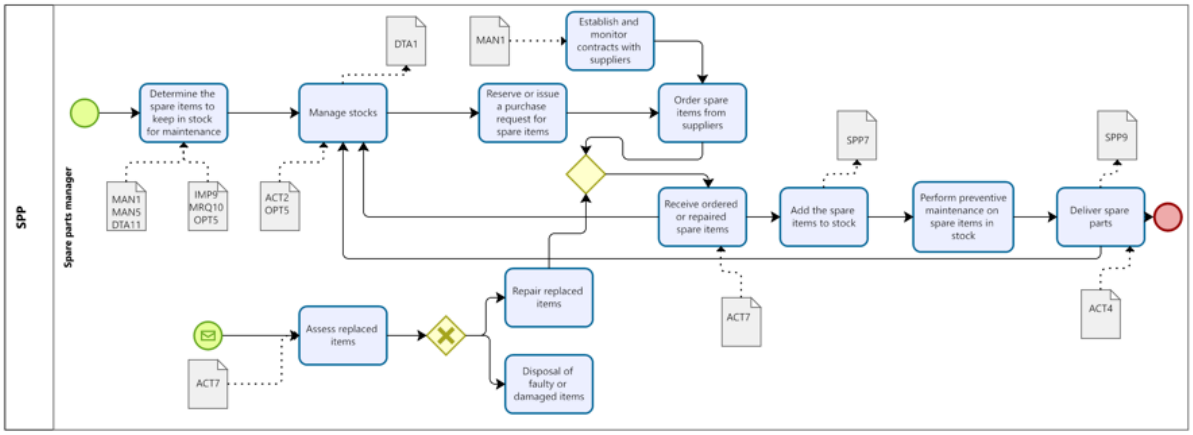

Figure 38 Spare parts process

Spare parts in the company are needed to perform maintenance tasks. These need to be stored according to the impact when stock is out, supply characteristics and inventory characteristics, this can be seen in Figure 38. The storage needs to be evaluated and reviewed based on the forecast demand. This is done in the first task of the process (Oliveira et al., 2019). The subprocess is about ordering new spare parts and contacting the suppliers that deliver these items. This subprocess needs to work properly to perform maintenance tasks on time.

Communication with other processes

For determining the spare parts needed in stock different documents are used. The strategy and budgeting from the company board, MAN1 and MAN5. The DTA11 from the history of the stock on different spare parts. The improvements on assets MRQ10 and IMP9 are needed when an improvement will be done and there is still stock on the “old” asset’s spare parts. Finally, the OPT5 is for the improvement of the process itself. ACT2 is a request for spare parts needed for a maintenance task by the Planner. ACT7 is the part that was retrieved after replacing it, this is an object. MAN1 is also used for contact with the suppliers, the spare parts manager can then follow the strategy of the company board. ACT4 is the actual collection of the spare parts.

External Services (SER)

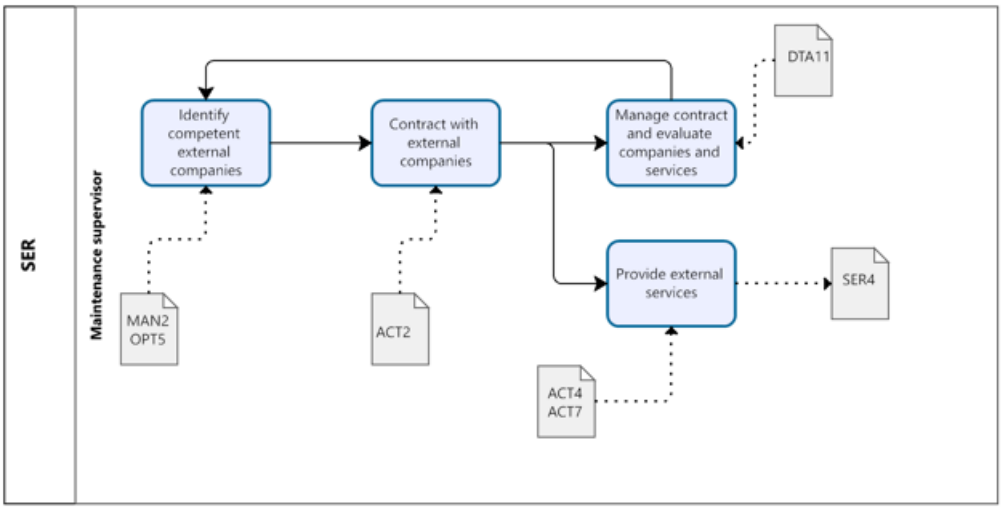

Figure 39 External services process

The service subprocess is about the contact with External Contractors, depicted in Figure 39. This needs to be performed correctly to keep close and good contact with the contractors.

Communication with other processes

The company board identifies external companies to use as External Contractors, this is shown as MAN2. OPT5 is again the optimization of the process itself. Next, the contact with the External Contractors is done in ACT2 and with that information, a contract is made. The feedback on the performed maintenance tasks is shown as ACT4 and ACT7. These are documents from the performance of the maintenance tasks. The data provided by the subprocess, DTA11, is used to evaluate the contracts and services of external companies.

Evaluation of the maintenance model

In the evaluation process, there is looked at the expert opinion and the maintenance maturity model. Improvements were made accordingly to fully fulfil the needs and demands of the experts and the models.

Experts review

The expert review is carried out with two maintenance experts of Catch22. This was an iterative process where the first time we met improvements were made for making it more realistic. The total maintenance model looked good and it was something they could use. The steps needed in all the processes were something that they did not have in mind, but with an explanation, they also found it needed to let the task stand because it could help to give insight into the steps that needed to be performed.

Maintenance maturity model

The maintenance model made in this chapter is tested on the maintenance maturity model mentioned in chapter 2. The model is tested, improved and evaluated to get the best results and is a fully mature model. The test scores can be seen in Figure 40. The scores are explained in Table 2 Maturity of the maintenance model according to maturity model 1. The use of the CMMS as an automated system is an assumption made because without it a fully mature maintenance model is

not possible. Therefore, the assumption is made that the model will have this and therefore is fully mature.

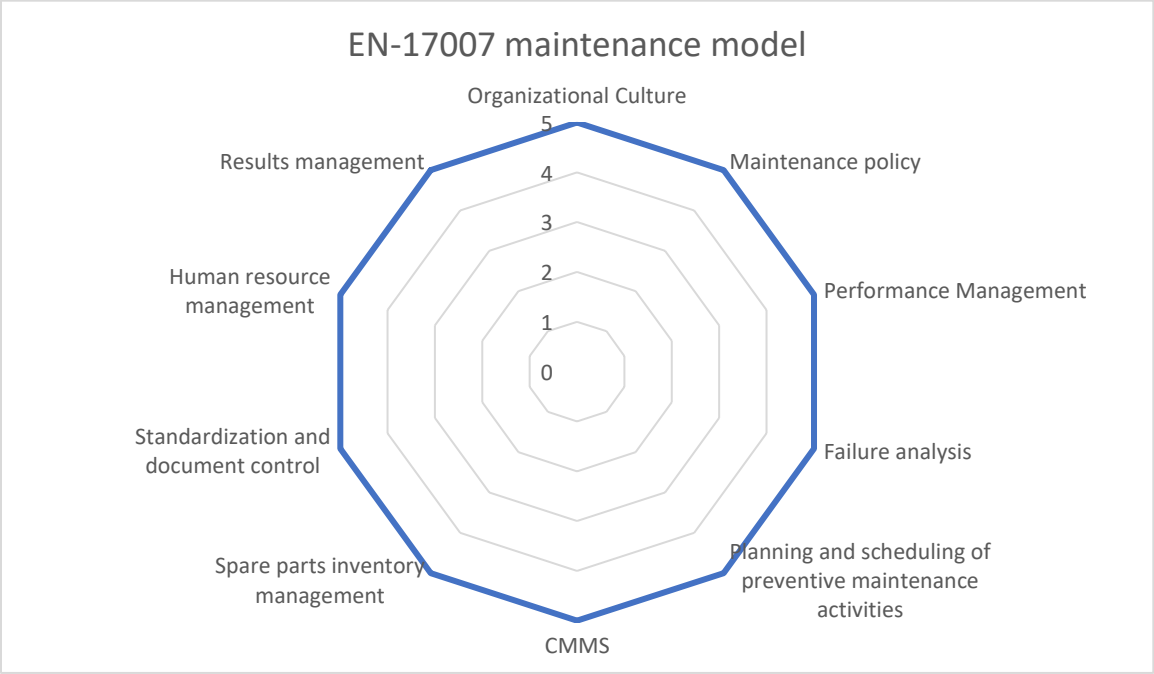

Figure 40 Radar chart of the maturity of the maintenance model according to maturity model 1

Table 2 Maturity of the maintenance model according to maturity model 1

Measurement class	**Level**
Organizational culture	Due to the subprocess OPT and the tasks of improvement and adaptation of found results the score is the highest. All the processes adapt to the new strategic priorities when needed, which are MAN1.
Maintenance policy	The whole process of the maintenance tasks is to improve quality and reduce accidents, subprocess HSE and Acting on the maintenance tasks. The preventive maintenance process results increase in productivity and reduce costs. The OPT and MRQ are for the improvement of processes and equipment, respectively.
Performance management	The management board defines goals and objectives as well as a strategy. The DATA and DOC will result in analysing the collected data and improving the project.
Failure analysis	In the corrective and preventive maintenance process are taken into account the failure analysis when an accident occurs. This is a standard task in the process.
Planning and scheduling of the preventive maintenance	In the preventive maintenance process, an updated schedule is made according to collected data on equipment. The Planner and Scheduler take into account the production and correctness of the schedule of the maintenance jobs.
CMMS	The DATA process suggests having an automated system which communicates with all other processes.
Spare parts inventory management	The subprocess SPP complies with the inventory management required for level 5.
Standardization and document control	The DOC process will make sure that all documentation is recorded in the same way and is updated accordingly.

Human resource management	The SER process makes sure that all personnel is trained accordingly or personnel is hired.
Results management	Due to all the processes the costs are reduced and this is checked by the BUD process and the management board to fit the strategy and objective made.

The maintenance maturity model that is used for the evaluation is maturity model 2, as stated in chapter 2 (Tortora et al., 2022). The table can be seen in Table 3 The maturity of the maintenance model according to maturity model 2 is filled in accordingly. The highest level is reached so the model is fully mature. There is uncertainty because it is expected that computerized systems will be used in the maintenance processes. This is not made specific in the processes but this is a necessary step to be fully mature.

Table 3 The maturity of the maintenance model according to maturity model 2

Criteria	Level
1WHAT EQUIPMENT	The highest level is reached because of the clear and updated documents on the equipment. This is the result of the subprocesses
HOW EQUIPMENT	Due to the subprocesses, the files and information are available, updated and correctly managed.
WHICH EQUIPMENT	To be able to comply with the tasks in the subprocesses a maintenance system should be applied. Also, the data transfer between all processes can be seen in the total maintenance process, where DATA9 is widely used.
WHEN EQUIPMENT	Due to the subprocess MRQ, the data on this is updated and checked with suppliers.
WHO EQUIPMENT	Due to the subprocess DOC and the subprocess DATA, this is done accordingly
WHAT MAINTENANCE PERSONNEL	Because of the subprocess RES and the subprocess DOC, this is done accordingly and expected to be the best of class when all the tasks are performed.
HOW MAINTENANCE PERSONNEL	Due to the DOC subprocess, this is well-organised and easy to retrieve information.
WHICH MAINTENANCE PERSONNEL	The subprocesses are expected to be as fully automated as possible and therefore are expected to be completely integrated.
WHEN MAINTENANCE PERSONNEL	Due to the subprocess DOC and the RES, this is done accordingly. Also, the planning itself is checked by another person and therefore correct.
WHO MAINTENANCE PERSONNEL	The subprocess DOC is performed by one person and specific tasks are assigned.
WHAT WORK ORDER DB work order request	Due to the subprocess, DOC the work order documentation is recorded correctly. Also, the steps followed for the work order are proper.
WHAT WORK ORDER DB work order	Due to the subprocess, DOC the work order documentation is recorded correctly. Also, the steps followed for the work order are proper.

WHICH work order management	The data collected in the subprocess DATA is mostly automized. The data is widely used in the company for other processes.
HOW work order management	The standard is applied to work orders.
WHAT EQUIPMENT REPORT	The data collection method is updated and improved according to the subprocess OPT.
WHAT MAINTENANCE PERSONNEL REPORT	Due to the subprocesses OPT, DATA and DOC the maintenance model complies with this standard.
WHAT WORK ORDER REPORT	Due to the subprocesses OPT, DATA and DOC the maintenance model complies with this standard.
HOW REPORTS	The DOC subprocess makes sure that a standard is established
WHICH REPORTS	The subprocesses are expected to be as fully automated as possible and therefore are expected to be completely integrated.
WHEN REPORTS	Due to the continuous analysis and improvement of the processes, the maintenance reports are analysed as needed.
WHO REPORTS	The subprocesses make sure there is specific personnel on the different tasks for the reports

4.3 Conclusion

The maintenance processes as presented in this chapter are expected to perform well on the variables, reliability, availability and OEE. The processes are according to the EN-17007. The maintenance process is been validated by the maintenance experts of Catch 22 and the maintenance literature of Terry Wireman is used to make the model more specific (Wireman, 1998) . The model is the basis on how the maintenance process should look like. The tasks in all the processes should be performed and registered ordinarily. In the models themselves, the assets of the specific companies and the input can be used to fit them into their companies. The total complete maintenance model can be found in Appendix A: The total maintenance model.

The total maintenance process is evaluated with the business maintenance maturity model 1 and 2 (Oliveira et al., 2019; Tortora et al., 2022). The scores are the highest because these models were also used in the decisions in the making of the model. The assumption on the automated system of collecting data and transferring data is made to be a fully mature maintenance model. The models as well as the maintenance model are used to make a table for giving scores on the maturity of a company according to its maintenance. The table can be seen in Appendix C: Fill in maintenance maturity model

5 Case study

In this chapter, we concentrate on answering Research Questions 5 and 6, i.e.,

1. *How well does Catch 22 customers' maintenance process fit concerning the optimal business process?*
2. *What are the recommendations to improve Catch 22 customers' maintenance process based on the optimal business process?*

5.1 Method

To respond to the aforementioned RQs, we conduct interviews with consultants of the company. The interview is performed with the maintenance consultant who is familiar with the procedures within the company. Another requirement is that the interviewed maintenance consultant is working at the company for a minimum of 3 months.

The interview is an unstructured interview which will be recorded for reference work. In the process, the interviewee is told about the procedure and the recording. The interview itself is performed by me. This is done by going through all the different parts in the optimal case of the maintenance process. Thereby the questions asked are about how the process is performed in the company. The difference is written down, to use for the recommendations. Afterwards, this is used as input for an analysis of whether the company can improve or not. In the recommendations, it is also stated how the company could start to improve the process.

The interview is addressing the processes in the following way:

- The manage maintenance process
- The preventive maintenance process
- The corrective maintenance process
- The acting and performing of both these processes
- The subprocesses

The processes are followed task by task. In this, the questions are asked whether the interviewee sees similarities or differences, and whether the documentation on these tasks is present. After completely handling one process, the interviewees are asked whether they find other problems in these processes. The focus of the tasks is communication between the departments and clear documentation. The answers are analysed and checked according to the maintenance maturity model Appendix C: Fill in maintenance maturity model. This appendix presents a table followed by the maintenance model made in chapter 4. The table helps to make a conclusion on which parts the company could improve.

Two companies are used in this research, both being medium-sized production companies in the food industry. From now on, they will be called company x and company y. Companies x and y handle the performance of maintenance differently: company x has a continuous maintenance process where tasks are performed along the way, while company y has a maintenance policy where they stop the production for a few months to perform maintenance (after this, company y goes back to the production steps).

5.2 Results

The interviews resulted in a few recommendations. Moreover, further research should be conducted for having specific and detailed recommendations. In some parts already improvements can be made.

In company x, a lot of improvements can be made in the backlog of the maintenance structure. Especially in the supporting departments. But it is a smaller company due to this fact a lot of processes are conducted by the same people.

Company x results

The management side is put aside because the knowledge of the interviewee is not sufficient to say something about this. Hence, we continue with the preventive maintenance process, which they still hope to put in operation in the future. At this time, the company is first getting clear what machines they have and for each machine determining the first maintenance steps.

We give advice to address the problems resulting from hidden causes. But the company addresses problems as they come. So, when the line is shut down, they will do some maintenance i.e., the maintenance personnel smear the bearings of the machines. Most companies do not address problems beforehand. Conversely, they will pay money when necessary. Thus, preventive could definitely save some money for them.

The processes of planning along with the frozen plan are seen in the company. The gathering of events is not a real process, but a lot of tasks that are done automatically. These processes are done based on the experience of the maintenance workers. So, when these people retire, the company can potentially have a problem. The installation lines sometimes stood still because the experienced employee is not present and the maintenance could not be performed. This also represents cost for the company in terms of time spent.

With corrective maintenance and high priority, every 48 hours, the company performs maintenance when needed. The company does not look into costs and benefits of the maintenance process, unless the maintenance worker tells the project manager that it is becoming very expensive.

The planning is done by 1 person and there are 2 Schedulers. The assets should be running 24/7 but this is difficult because these employees, the planner and work preparer only work from 9 to 5. Afterwards, a lot is done on experience. Therefore, the machines are not always running 24/7. Overall, the maintenance is performed based on when it comes in handy and not when it is needed.

The rest of the processes are similar. The procedures are not that specific in the work order and the documentation of each process could be improved. Only some tasks are present in the companies' processes.

The external contractor is working so often in the company that it is like an employee of the company. The necessary check-ups for the signing of the work order are either not done properly, or never done at all.

Subprocess

Most of the subprocesses are not performed in the company. The interesting part was about the spare parts. The company mostly has old assets or test models. Therefore, there are not many spare parts at hand and/or the suppliers are not supporting these assets anymore. This makes it a lot harder to perform maintenance.

Company y results

This company does most of the maintenance once every 6 months, and it makes a total shutdown for performing the maintenance tasks.

The preventive maintenance is similar as the proposed process in chapter 4. There are a few points that could be addressed and most of the points in preventive maintenance come from the corrective

maintenance. Research is performed regarding the types of breakdown that are more often and concerning what are the specific reasons behind this. The documentation is organised well, and the maintenance plan is provided by the supplier and updated by the company itself.

The corrective maintenance process of the company is also similar to the respective process proposed in chapter 4.

Preventive maintenance is not working with priorities, but corrective maintenance is. We thus recommend that priorities are considered also for preventive maintenance, as not all preventive tasks can be performed at the same time, so a selection should be made.

The planner has a similar role to that we propose, but there is a difference in their discipline. The planner and team leader are sometimes doing work for each other. They also do not have a scheduler in the company, but given the size of the company, we recommend that they hire one.

The maintenance procedures are present, but some things are still done based on the experience of the maintenance personnel. Most of the procedures are registered in SAP, but a few of them are not available anywhere.

The company is at the end also making a Plan-Do-Check-Act (PDCA) for analysing whether the part is still able to go on for another year. Otherwise, an improvement process is started.

Subprocess

The documentation process is present in the company, but the tasks are not the same as the ones we propose in the subprocesses of chapter 4. The documentation structure and the tasks that come with it could therefore be implemented and improved according to these proposed subprocesses.

The data process is present in company y, along with most of its tasks. The only recommended improvement here is to update the security systems more often. This is also an important task in the process, which means that this could eventually result in errors or issues. The errors and issues can be overcome by updating the system frequently and test the data structure.

The distribution of tools and the communication on where the tools can be improved. No standard system is now implemented for the distribution of the tools inside the company, which is also something to be done in the future.

5.3 Conclusion

The talks at the company worked quite well. Discussing the optimal case with the consultants so that they can compare it to their real live case was helpful. They can have further research done on some points, however without really making the AS-IS process and comparing this to the optimal maintenance process made is difficult. This is because you rely on the knowledge of the maintenance consultant of the company. This person knows a lot but not every specific detail. Thus, if we had had the time to do the complete AS-IS process model, then perhaps the case study would have been more conclusive. Still, a few recommendations can be made regarding where research should be done.

Company X is at the beginning of its maintenance management. They should hence investigate their documentation and clarify notations. This is needed to take the subsequent steps needed to improve their maintenance management process. After this, the documentation can be reviewed and analysed to find the problems. The documentation on how to perform maintenance should also be structured since they have a lot of experienced maintenance workers but have not documented what to do in each event. The company should also investigate the implementation of the subprocesses to

improve its maintenance management even more. They should first start with implementing the documentation and data process, and after this, they can improve the preventive and corrective maintenance process. Next, the other processes could be slowly implemented by first performing the basic task and next performing all the tasks presented in the given processes.

Company Y is a mature company in maintenance management. They have almost all the subprocesses present in the company, the preventive, corrective maintenance, and the maintenance tasks are all present in the company. There is a problem with the communication and distinction between the scheduler and the maintenance supervisor. They perform tasks for each other and do not check each other on the tasks. In this way, problems could arise when mistakes are made. Also, for the flow of the company, there must be a clear distinction between these employees. The subprocesses regarding improvement in the processes as well as small improvements in machines could be further looked into. The spare parts management and the reparation of spare parts back in storage is a process to look further into.

To conclude the maturity of company Y is between levels 2 and 3 where improvements can be made. The maturity of company X is between 1 and 2, where some points are at level 1 or even level 0 and some points are around level 2. The maturity model can be seen in the Appendix C: Fill in maintenance maturity model. The result of the filled-in maturity model is shown in Figure 41.

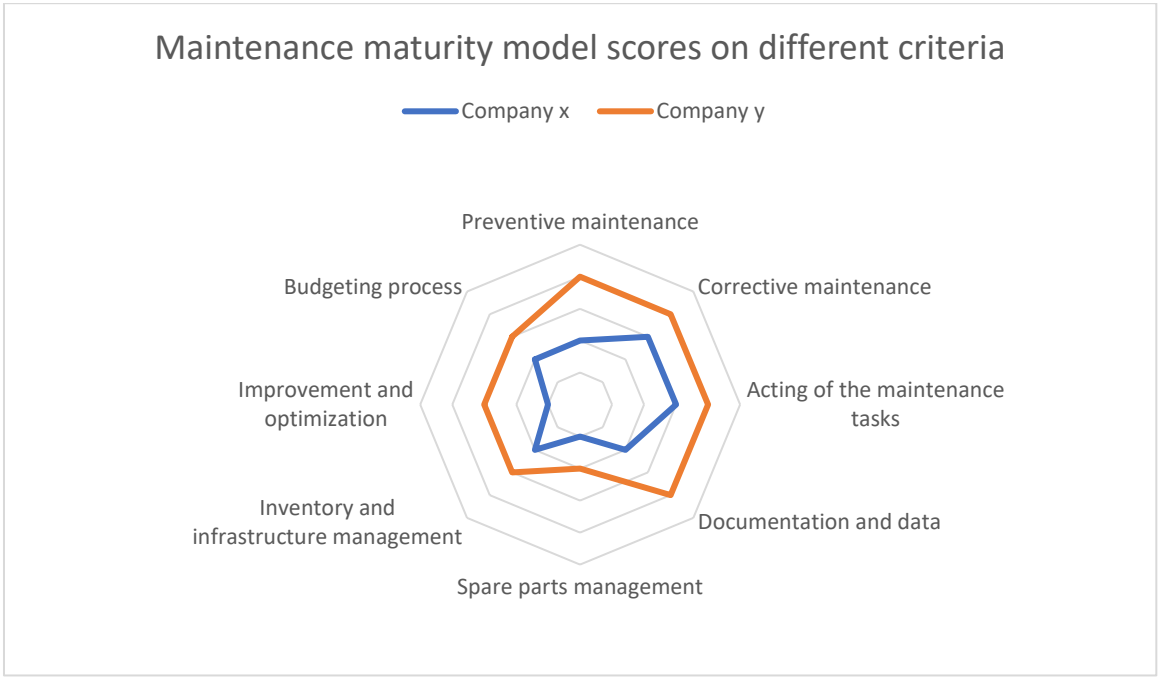

Figure 41 Maintenance maturity model scores of the companies

6 Conclusion and recommendations

In this chapter, the conclusion and recommendations are given. The answer is given to the main research question. After this, the discussion on the implantation of the model and further recommendations are discussed.

6.1Conclusion

Developing this research started with researching the standard EN-17007 and the processes that are presented in this. Then, the processes were elaborated on and specified. The proposed maintenance model was then evaluated by maintenance experts and by using maintenance maturity models. And finally, the maintenance model was tested in two small case studies at companies that are clients of Catch 22. This results in answering the main research question, as follows:

How can an optimal maintenance process be made for a medium sized company in different levels of detail following the EN-17007?

First, the maintenance processes presented in the final model have been positively evaluated by using maintenance maturity models and the maintenance experts' opinions. The different levels of the maintenance process can be found in the top level of the collaboration model of the maintenance models which specify the communication between all the subprocesses. This follows exactly what the EN-17007 standard defines. The subprocesses are there to support the two main process, which are the preventive and corrective maintenance processes. The communication between these with a clear strategy gives the companies the possibility to have an optimal maintenance process.

The model gives insight into the maintenance processes that are needed in a company. The maintenance model is general and can therefore be used in any company with a few modifications. These depend on the strategy adopted by the company board. However, the tasks presented in the processes should all be present in some way or another for the company to be considered a fully mature maintenance company.

By testing the model on two companies, the maintenance model came to use and some advice was given to the companies on how they could improve their maintenance processes. The maintenance processes presented in this thesis were a guideline for the maintenance consultants and provided, as they said, insight into how the maintenance process could look like.

So, to conclude the complete maintenance process model is presented in Appendix A: The total maintenance model, and each of the subprocesses, described in Chapter 4. The optimal maintenance process developed according to the NEN17007 can be used by companies to try and compare their maintenance process with the maintenance process described in this thesis. This should result in an effective analysis of what is done well and what is missing, leading to improvements in the company's maintenance process.

6.2 Discussion

The maintenance model can be used in different ways in Catch 22. The first is the application of what is already presented in this research, i.e., using the maintenance model as guideline for the evaluation of the maintenance processes within a company that is a client or wants to be a client of Catch 22. The discussion about the process should help to provide insight for the company as well as to locate the possible problems for the consultants of Catch 22.

Another application of the maintenance model presented in this research is using it as a learning tool for new consultants at Catch 22, or for personnel who are not familiar with the EN-17007 standard. The new consultants could have a fast-learning curve on how a maintenance model should look, without having the experience of a maintenance expert. They can therefore provide advice faster and be used as a maintenance consultant faster. Also, the application of using it as a learning tool for the EN-17007 is useful for Catch 22. By this, they can sell to the customers of Catch 22, so that all their maintenance consultants are familiar with the EN-17007 standard and can apply this standard to their maintenance processes.

The usage of the model can be done in the same way as the case study is presented by walking through the whole process. Another application of the maintenance model presented, is by making an as-is model and using the maintenance model as a guideline for improvements. Companies can implement and compare the results to improve and comply. When using the maintenance model, it is important to make clear the size of the company and strategy of the company. There could be differences between the presented model and the optimal model for that specific company. Therefore, it is important to use it as guideline and not implement it directly without taking into consideration the specific requirement of the Catch 22 client.

6.3 Recommendations and future research

In this section, the recommendations for Catch 22 are discussed as well as possible future research into maintenance processes.

6.3.1 Recommendations

The recommendations for Catch 22 is to have the model widely tested among their client bases. The research can be about testing of this maintenance model in more case studies and doing a full research where the as-is model is made for the company that is researched and to investigate the possibilities of implementing all the tasks proposed in this thesis's maintenance model. This helps to improve the methodology of testing the model in Catch 22 customers.

Another recommendation is to look into the differences between the model when applying it to smaller companies and larger companies in the clientele of Catch 22. This can be done by looking into larger and smaller companies and testing the model. When differences are found, the implementation of the tasks given in this research should also take into consideration if the tasks are fit for the company size.

6.3.2 Future research

Future research could be performed concerning a different standard and a comparison could be made between the outcome of these models. This helps to make the optimal model compliant with multiple standards.

The different subprocesses discussed in this research are not that specific. Therefore, further research can be performed in the processes like, spare parts process, data management and documentation. Especially in the direction of how this in real life will look like and examples of documentation and storage. This may be combined with looking further into the developments of industry 4.0 where the sensors and data are widely implemented in the maintenance processes and what the impact is for the maintenance processes presented in this research.

6.4 Limitations

We do acknowledge that there are limitations in the model itself, but also in the process and the use of the model in the companies. Moreover, we need to take into account possible problems with the interview.

The limitation of the model and difficulties were found because assumptions had to be made. This was the case with the company size and the assets, as well as making the model general. This came with difficulties for the researcher because the process should be made according to facts and trade-offs. Due to this, some improvements can be missed.

The validation of the model is also a limited, since an assumption is made that the applied maintenance maturity models are good. Also, only using two models for testing can be a limitation and some improvements to make the model optimal can be missed. The validation with the maintenance experts can also be seen as insufficient. The maintenance experts are from Catch 22 and can therefore be biased. Also, the knowledge of the maintenance experts can be limited because they have been working on projects inside the same maintenance consultancy company.

There were some problems with the interview, for instance, not all the required information was known by the interviewees. This was especially the case for the maintenance management process. Therefore, conversations should be held with the higher management of the company. This was not possible for the companies but when using this maintenance model, the whole process should be validated.

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Appendix A: The total maintenance model

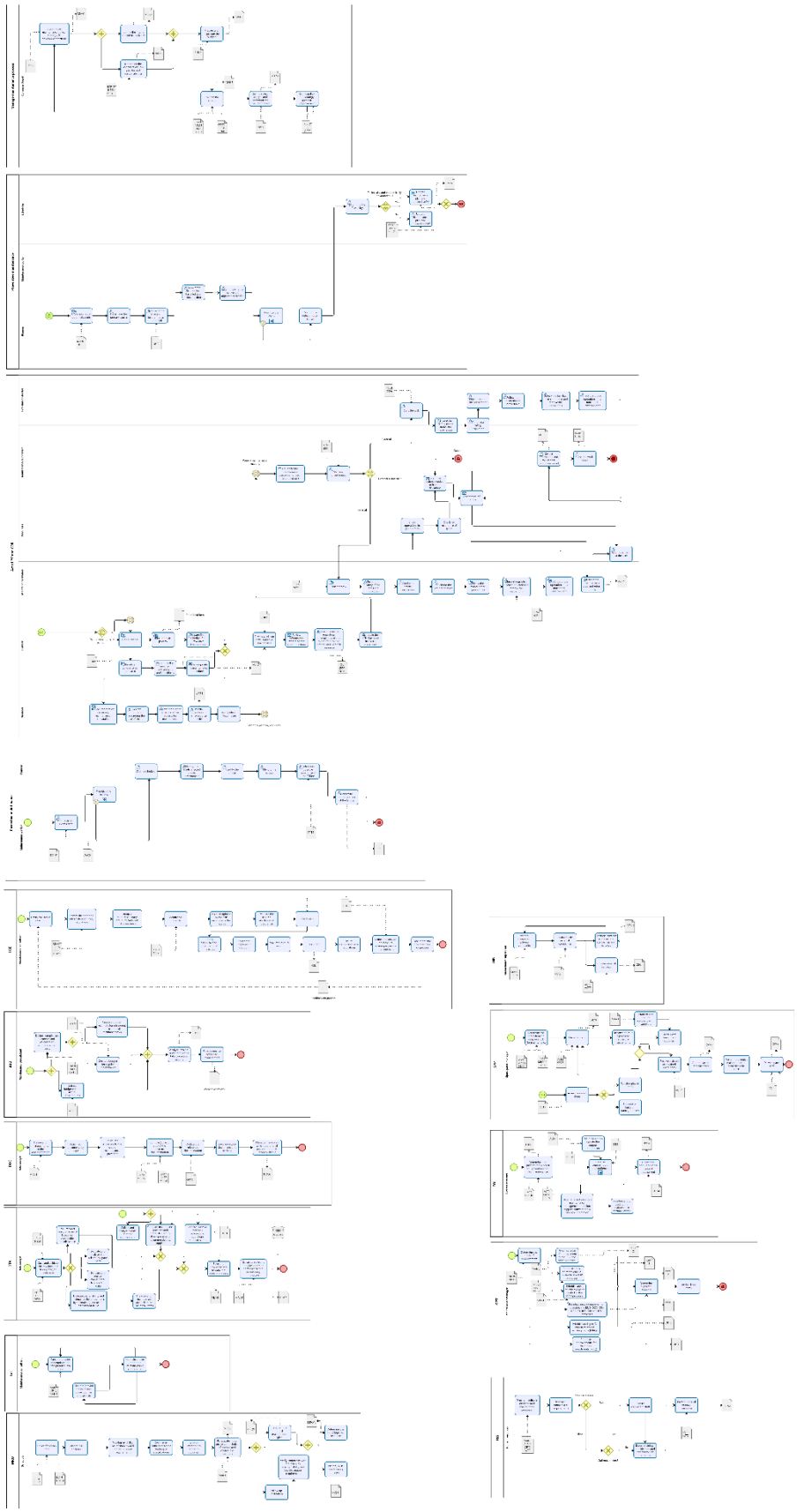

Figure 42 The total maintenance model according EN-17007

Appendix B: Maintenance maturity models

B.1 Maintenance maturity model 1

Measurement class	Level 1	Level 2	Level 3	Level 4	Level 5
Organizational culture	Changes are not well accepted. There is no guidance for continuous improvement and teamwork	Changes are accepted reluctantly. The need for continuous improvement was Identified, but not yet adopted. Limited teamwork	Changes are accepted and considered important. Implementation of actions for continuous improvement. Teamwork	Changes are accepted and considered important. Actions for continuous improvement with defined methodologies. Teamwork. Team spirit	There is commitment to the change, adapting to the new strategic priorities. Actions for continuous improvement with defined methodologies. Teamwork. Team spirit
Maintenance policy	Maintenance is considered a necessary evil, being focused on the resolution of faults in the shortest possible time	Maintenance is considered a necessary evil, but the need to act preventively is recognized	Maintenance is considered important in achieving the organization's objectives. Preventive maintenance in order to increase productivity and reduce costs	Maintenance is considered important in achieving the organization's objectives. Acting proactively (including improving equipment) in order to increase productivity, reduce costs and improve quality	Maintenance is considered a strategic function. Acting proactively (including improving equipment) and efficiently in order to increase productivity, reduce costs, improve quality and reduce accidents and environmental impact
Performance management	There are no defined indicators	Performance indicators calculated sporadically, with a focus on technical indicators determined for the all factory and/or at the production line level	Performance indicators calculated periodically, with a focus on technical and economic indicators, determined for the all factory, at the line and equipment level	Technical, economic and organizational indicators calculated and analyzed periodically, supporting decision making and giving rise sporadically to improvement projects; reliable data	Technical, economic and organizational indicators aligned with the strategic objectives of the organization, calculated and analyzed periodically, supporting decision making and giving rise to improvement projects; reliable data
Failure analysis	Failures analysis without a defined method, performed when failures with significant impact occur	Failures analysis without a defined method, performed sporadically and when failures with significant impact occur	Periodic failures analysis based on a defined method	Identification of critical equipment and critical failures sporadically and implementation of measures based on a methodical analysis of failures that causes a low recurrence of failures	Updated information of critical equipment and critical failures, and implementation of measures based on a methodical analysis of failures, which leads to the absence of fault recurrence
Planning and scheduling of preventive maintenance activities	Preventive activities defined following the occurrence of critical events	Planning carried out based on the manufacturer's manuals covering some equipment. Delays and programmed actions not completed	Planning carried out based on the manufacturer's manuals covering all equipment. Delays and programmed actions not completed	Revised activity planning based on failure rate and equipment monitoring. Occasional deviations in plans fulfillment	Revised activity planning based on failure rate and equipment monitoring. Programming defined based on planned production
Measurement class	Level 1	Level 2	Level 3	Level 4	Level 5
CMMS	No electronic records of maintenance data	Use of computer applications for maintenance management, not integrated with other computer systems of the company	Computerized system for planning and control of maintenance, with some unused functions, not integrated with other computer systems of the company	CMMS where not all functions available are widely and properly used, not integrated with other systems of the company	CMMS to support all functions of maintenance management, with a high degree of automation, whose functions available are effectively used, integrated with other systems of the company
Spare parts inventory management	Spare parts are not classified. There is no forecast of future demand	Classification of spare parts based on only one criterion (e. g. price or consumption pattern). Demand forecasts based on historical consumption	Classification of spare parts based on only one criterion (e.g. price or consumption pattern). Demand forecasts defined empirically and based on historical consumption	Classification of spare parts based on more than one criterion related to spare parts supply characteristics (e.g. lead time, suppliers) and/or inventory characteristics (e.g. price, obsolescence). Demand forecasts based on historical consumption, spare parts lifetime and maintenance strategy	Classification of spare parts based on their functionalities (impact of stock out), supply characteristics and inventory characteristics. Inventory management strategy defined for each group of the classification. Inventory levels regularly reviewed based on forecast demand, defined based on spare parts lifetime and maintenance strategy
Standardization and document control	Documentation of equipment unavailable or outdated. Non-standardized processes and activities	Documentation of equipment and processes are unorganized. Some processes and activities are standardized, but not revised	Documentation of equipment and processes are organized. Most processes and activities are standardized, but not revised	Documentation of equipment and processes are organized, with quick and easy access. Processes and activities are standardized and revised	Documentation of equipment and processes are systematically updated with quick and easy access. Processes and activities are standardized and systematically revised
Human resource management	Punctual training motivated by high-impact problems. Employees have low competence	Skills development plan for maintenance employees nonaligned with the area's needs	Skills development plan aligned with the area's needs	Skills development plan aligned with the area's needs. Polyvalent maintenance employees, with involvement of production employees in certain activities	Skills development plan aligned with the objectives of the area. Polyvalent maintenance employees, involved in improvement activities. Involvement of production employees in certain activities. Plans for recognition and reward
Results management (maintenance costs and quality)	High and uncontrolled cost; high waste of materials and high recurrence of failures	High and uncontrolled cost, with some actions performed sporadically to reduce waste and recurrence of failures	Implementation of actions to control costs, with level of waste and recurrence of failures measured but not investigated	Controlled costs, with level of waste and recurrence of failures measured and investigated	Controlled costs, low waste and low recurrence of failures

Figure 43 Maintenance maturity model 1 (Oliveira et al., 2019)

B.2 Maintenance maturity model 2

Table 4 Maintenance maturity model 2 (Tortora et al., 2022)

	Lev. 0-1	Lev. 1-2	Lev. 2-3	Lev. 3-4

WHAT EQUIPMENT	Some files regarding the physical and technical condition of the machines are available within the organisation. The information management practices regarding the equipment are basic.	Some files regarding the physical and technical condition of the machines and some machine failure data are available within the organisation. The information management practices regarding the equipment are basic.	Some files regarding the physical and technical condition of the machines and some machine failure and maintenance data are available within the organisation. The information management practices regarding the equipment are increasing.	All files regarding the physical and technical condition of the machines and all machine failure and maintenance data are available within the organisation. An improvement programme is prepared by the company. The information management practices regarding the equipment are the best in class.
HOW EQUIPMENT	Most machine maintenance equipment files and documents are not readily available. The methodological skills of the company are low.	Most machine maintenance equipment files and document are available but not complete and standardised. The methodological skills of the company are low.	Most equipment maintenance files are unique, consistent, and reliable, regardless of the storage period or the frequency of access. The information available is not redundant.	Most equipment maintenance files are complete, standardised and well-organised for access and retrieval. The information available is significant and correctly managed.
WHICH EQUIPMENT	The support used for the collection of most data is papery. This approach demonstrates poor company technological capabilities, which leads to the waste of resources and many inefficiencies in data and information management.	The support used for the collection of most maintenance files is an autonomous system for maintenance management that is not integrated with other systems. It is a stand-alone application for the management of only maintenance interventions. The company's technological skills are in an initial phase.	The support used for the collection of most maintenance files is an electronic software that can be interfaced with other company systems (for example, Enterprise Asset Management [EAM], CMMS or ERP). The software includes more features than an autonomous management system and this demonstrates the increase of company technological capabilities with a reduction in waste and inefficiencies towards an integration, albeit initial, between different functions.	The support used for the collection of most maintenance files is electronic (CMMS, ERP or EAM) and completely integrated with other company systems. It is a maintenance application system that is completely integrated with all the company's systems. There is a complete exchange of data/information between all company systems. This allows the company to have perfectly synchronised processes and achieve excellent performance. High degree of automation.
WHEN EQUIPMENT	Most machine maintenance files and documents are not updated when needed. Outdated information compromises the integrity and reliability of the database itself.	Most machine maintenance files and documents are updated in a long-term period, within an upgrade period greater than one year.	Most machine maintenance files and documents are updated in a medium-short term period, within an upgrade period between one year and six months.	Most machine maintenance files and documents are updated as needed.

WHO EQUIPMENT	There isn't a specific employee who takes care of equipment maintenance files' correct management.			There is a specific employee who takes care of equipment maintenance files' correct management.
WHAT MAINTENANCE PERSONNEL	Very few documents and/or systems interested in the management of 'maintenance personnel are available within the organisation. The information management practices regarding the equipment are really basic.	Not many documents and/or systems interested in the management of 'maintenance personnel' are available within the organization. The information management practices regarding the equipment are really basic.	Most documents and/or systems interested with the management of 'maintenance personnel' are available within the organisation. The information management practices regarding the equipment are increasing.	All the documents and/or systems interested with the management of 'maintenance personnel' are available within the organisation. The information management practices regarding the equipment are the best in class.
HOW MAINTENANCE PERSONNEL	Most of maintenance personnel documents and/or most of systems are not readily available. The methodological skills of the company are low.	Most of maintenance personnel documents and/or most of the systems are available but not complete and standardised. The methodological skills of the company are low.	Most of maintenance personnel documents and/or most of systems are unique, consistent, and reliable, regardless of the storage period or the frequency of access. The information available is not redundant.	Most of maintenance personnel documents and/or most of systems are complete, standardised, and well-organised for access and retrieval. The information available is significant and correctly managed.
WHICH MAINTENANCE PERSONNEL	The support used for the collection of most of the data is papery. This approach demonstrates poor company technological capabilities, which leads to the waste of resources and many inefficiencies in data and information management.	The support used for the collection of most of the maintenance personnel documents is an autonomous system for maintenance management that is not integrated with other systems. It is a stand-alone application for the management of only maintenance interventions. The company's technological skills appear to be in an initial phase.	The support used for the collection of most the of maintenance personnel documents is an electronic software that can be interfaced with other company systems (for example Enterprise Asset Management [EAM], CMMS or ERP). The software includes more features than an autonomous management system and this demonstrates the increase of company technological capabilities with a reduction in waste and inefficiencies towards an integration, albeit initial, between different functions.	The support used for the collection of most of the maintenance personnel documents is electronic (CMMS, ERP or EAM) and completely integrated with other company systems. It is a maintenance application system that is completely integrated with all the company's systems. There is a complete exchange of data/information among all company systems. This allows the company to have perfectly synchronised processes and achieve excellent performance. High degree of automation.

WHEN MAINTENANCE PERSONNEL	Most of maintenance personnel documents are not updated when needed and maintenance personnel systems are not scheduled when needed. Outdated information compromises the integrity and reliability of the database itself.	Most of maintenance personnel documents are updated in a long-term period, within an upgrade period greater than one year, and the maintenance personnel systems are scheduled on an optional basis.	Most of maintenance personnel documents are updated in a medium-short term period, within an upgrade period between six months and one year and the maintenance personnel systems are scheduled on a rare or irregular basis.	Most of maintenance personnel documents are updated as needed, constantly, and the maintenance personnel systems are scheduled as needed.
WHO MAINTENANCE PERSONNEL	There isn't a specific employee who takes care of some/all maintenance personnel files' correct management.			There is a specific employee who takes care of some/all maintenance personnel files' correct management.
WHAT WORK ORDER DB work order request	The company does not have an efficient and effective maintenance work order management system. The company uses a work order request that provides little useful information to the Planner. The organisation has poor methodological capabilities.	The company does not have an efficient and effective maintenance work order management system. The company uses a work order request that does not provide all the useful information to the Planner. The organisation has poor methodological capabilities.	The company has an efficient and effective maintenance work order management system. The company uses a work order request that provides almost all useful information to the Planner. The organisation has good methodological capabilities.	The company has an efficient and effective maintenance work order management system. The company uses a work order request that provides all useful information to the Planner. The organisation has the best methodological capabilities.
WHAT WORK ORDER DB work order	The company does not have an efficient and effective maintenance work order management system. It uses a work order that provides little useful information to the maintenance technician to perform the maintenance intervention properly. The organisation has poor methodological capabilities.	The company does not have an efficient and effective maintenance work order management system. It uses a work order that does not provide all useful information to the maintenance technician to perform the maintenance intervention properly. The organisation has poor methodological capabilities.	The company has an efficient and effective maintenance work order management system. It uses a work order that provides almost all useful information to the maintenance technician to perform the maintenance intervention properly. The organisation has good methodological capabilities.	The company has an efficient and effective maintenance work order management system. It uses a work order that provides all useful information to the maintenance technician to perform the maintenance intervention properly. The organisation has the best methodological capabilities.
WHICH work order management	The support used for the management of work order and/or work order request is mainly papery. This approach	The support used for the collection of work orders and/or work order request data is mainly an autonomous system	The support used for the collection of work orders and/or work request data is mainly an electronic software that can be	The support used for the collection of work orders and/or work request data is mainly electronic (CMMS, ERP or EAM) and

	demonstrates poor company technological capabilities, which leads to waste of resources and many inefficiencies in data and information management.	for maintenance management that is not integrated with other systems. It is a stand-alone application for the management of only maintenance interventions. The company's technological skills appear to be in an initial phase.	interfaced with other company systems (for example Enterprise Asset Management [EAM], CMMS or ERP). The software includes more features than an autonomous management system and this demonstrates the increase of company technological capabilities with a reduction in waste and inefficiencies towards an integration, albeit initial, among different functions.	completely integrated with other company systems. It is a maintenance application system that is completely integrated with all company's systems. There is a complete exchange of data/information between all company systems. This allows the company to have perfectly synchronised processes and achieve excellent performance. High degree of automation.
HOW work order management	A standard has not been established for the management of maintenance work orders.			A standard has been established for the management of maintenance work orders.
WHAT EQUIPMENT REPORT	The company does not have an efficient and effective reporting management system. It creates very few reports related to the equipment that records and monitors little data. This does not allow for the creation of meaningful statistics that can support the decision-making process. The organisation has poor methodological capabilities.	The company does not have an efficient and effective reporting management system. It does not create all reports related to the equipment that records and monitors little data. This does not allow for the creation of meaningful statistics that can support the decision-making process. The organisation has poor methodological capabilities.	The company has an efficient and effective reporting management system. It creates almost all reports related to the equipment that records and monitors much data. This allows for the creation of meaningful statistics that can support the decision-making process. The organisation has good methodological capabilities.	The company has an efficient and effective reporting management system. It creates all reports related to the equipment that records and monitors all data. This allows for the creation of meaningful statistics that can support the decision-making process. The organisation has the best methodological capabilities.
WHAT MAINTENANCE PERSONNEL REPORT	The company does not have an efficient and effective reporting management system. It creates very few reports related to the maintenance personnel who record and monitor little data. This does not allow for the creation of meaningful statistics that can support the decision-making process. The	The company does not have an efficient and effective reporting management system. It does not create all reports related to the maintenance personnel who record and monitor little data. This does not allow for the creation of meaningful statistics that can support the decision-making process. The	The company has an efficient and effective reporting management system. It creates almost all reports related to the maintenance personnel who record and monitor much data. This allows for the creation of meaningful statistics that can support the decision-making process. The organisation has	The company has an efficient and effective reporting management system. It creates all reports related to the maintenance personnel who record and monitor all data. This allows for the creation of meaningful statistics that can support the decision-making process. The organisation has the best methodological capabilities.

	organisation has poor methodological capabilities.	organisation has poor methodological capabilities.	good methodological capabilities.	
WHAT WORK ORDER REPORT	The company does not have an efficient and effective reporting management system. It creates very few reports related to the maintenance work order that records and monitors little data. This does not allow for the creation of meaningful statistics that can improve the work order management process. The organisation has poor methodological capabilities.	The company does not have an efficient and effective reporting management system. It does not create all reports related to the maintenance work order that records and monitors little data. This does not allow for the creation of meaningful statistics that can improve the work order management process. The organisation has poor methodological capabilities.	The company has an efficient and effective reporting management system. It creates almost all reports related to the maintenance work order that records and monitors much data. This allows for the creation of meaningful statistics that can improve the work order process. The organisation has good methodological capabilities.	The company has an efficient and effective reporting management system. It creates all reports related to the maintenance work order that records and monitors all data. This allows for the creation of meaningful statistics that can improve the work order process. The organisation has the best methodological capabilities.
HOW REPORTS	A standard has not been established for the management of maintenance reports.			A standard has been established for the management of maintenance reports.
WHICH REPORTS	The support used for the collection of reports is mainly papery. This approach demonstrates poor company technological capabilities, which leads to waste of resources and many inefficiencies in data and information management.	The support used for the collection of reports is mainly an autonomous system for maintenance management that is not integrated with other systems. It is a stand-alone application for the management of only maintenance interventions. The company's technological skills appear to be in an initial phase.	The support used for the collection of reports is mainly an electronic software that can be interfaced with other company systems (for example Enterprise Asset Management [EAM], CMMS or ERP). The software includes more features than an autonomous management system and this demonstrates the increase of company technological capabilities with a reduction in waste and inefficiencies towards an integration, albeit initial, between different functions.	The support used for the collection of reports is mainly electronic (CMMS, ERP or EAM) and completely integrated with other company systems. It is a maintenance application system that is completely integrated with all company's system. There is a complete exchange of data/information among all company systems. This allows the company to have perfectly synchronised processes and achieve excellent performance. High degree of automation.
WHEN REPORTS	Most of the maintenance reports are not analysed when needed. Outdated information compromises the	Most of the maintenance reports are analysed in a long-term period, within an analysis period	Most of the maintenance reports are analysed in a medium-short term period, within an analysis period	The maintenance reports are analysed as needed.

	integrity and reliability of the database itself.	greater than one year.	between six months and one year.	
WHO REPORTS	There isn't a specific employee who takes care of maintenance reports' correct management.			There is a specific employee who takes care of maintenance reports' correct management.

Appendix C: Fill in maintenance maturity model

Table 5 Table of criteria on the made maintenance model processes

Measurement criteria (processes)	Level 0	Level 1	Level 2	Level 3	Level 4
Preventive maintenance	No tasks are present from the preventive maintenance process	Some tasks are present in the preventive maintenance process	Most tasks are present in the preventive maintenance process	Almost all tasks are implemented from the preventive maintenance process	All the tasks are present and communicate with other processes is perfect. The planning is revised based on planned production.
Corrective maintenance	No tasks are present from the corrective maintenance process	Some tasks are present in the corrective maintenance process	Most tasks are present in the corrective maintenance process	Almost all tasks are implemented from the corrective maintenance process	All the tasks are present and communicate with other processes is perfect.
The acting of the maintenance tasks	Almost no tasks are present and the maintenance is performed ad-hoc.	Some tasks are present but not done properly and in the same way.	Most tasks are present and the tasks of maintenance are mostly done in the same way	Almost all tasks are implemented and the maintenance is performed in the same way but the documentation is not overall present	The maintenance tasks are performed accordingly and the documentation is registered. Also, the different tasks are distributed along the personnel.
Documentation and data management	No documentation or standardization is present. Data management is not performed	Documentation is present on some assets but not organized and some standardization is done	Documentation and data are collected but not revised. The documentation is organized	Almost all tasks are done and the documentation is standardized. The data analysation is not performed on all parts.	The documentation is done according to a prescribed way and updated. The data management is on top of the class and saved and

					analysed when needed.
Spare parts management	There is no spare parts management and the tasks are not present	There is a criterion for spare parts storage. There is no forecast demand planning but only based on historical data.	Most tasks are present. There is a classification of the spare parts and the demand is based on a forecast.	Almost all tasks are implemented and the spare parts are stored based on more criteria. Also, the forecast is based on historical data.	The spare parts are stored following storage guidelines and the tasks for maintenance on the tasks are performed properly.
Inventory and infrastructure management	No tasks on inventory and infrastructure are implanted	Almost no tasks on inventory and infrastructure processes are implanted	Some tasks on inventory and infrastructure processes are implanted	Most of the tasks on inventory and infrastructure processes are implanted	The inventory of assets and tools is checked regularly and the infrastructure is updated and documented properly.
Improvement and optimization	No improvement process is present and no optimization is performed.	Improvement is done sporadically and no optimization is done	Some improvement is performed but no clear process is present	Almost all the processes are evaluated and improved when needed.	The processes are evaluated and improved when needed. This also counts for the assets, tools, and spare parts.
Budgeting process	The costs are high and uncontrolled. The occurrence of failures is high and therefore the costs are too. High waste of materials	Almost no tasks are implemented. The costs are high and some cost reduction is made on failures.	Some of the tasks are implemented. Measurement of costs is collected.	Most of the tasks are implemented. Controlled cost with the waste and failure costs analysed.	The budgets are analysed and updated and follow the strategy of the company. The choices made are with insight into the possible risks.