Design of a maintenance Performance Measurement System for Performance Based Contracts

A case study of maintenance at the Zor-f plant

By

R. (Ragnhild) van Rijn
4138791

TIL 5060 - Master Thesis Project
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Report number: 2017.TIL.8120
Contact details: ragnhildvanrijn@gmail.com

Graduation Committee:

Dr. R.R. Negenborn	Chair	TU Delft, faculty 3ME
Dr. W.W.A. Beelaerts van Blokland	Supervisor	TU Delft, faculty 3ME
Dr. M.W. Ludema	Supervisor	TU Delft, faculty TBM
Drs. N.W. Meerdink	External supervisor	Stork

Preface

In the Netherlands nearly 11 daily doses of antibiotics are used per 1000 inhabitants (Centraal Bureau voor de Statistiek, 2016). Despite, many people use antibiotics, few people are aware how antibiotic is produced. During this project I got the opportunity to learn more about the production process of an semi-finished product of antibiotics and the maintenance that is related to this production process.

This report lying in front of you has been written in the context of the course *TIL 5060- Master Thesis Project,* part of the Master Transport, Infrastructure and Logistics of Delft University of Technology. By completing this course, I complete also the master Transport, Infrastructure and Logistics. This project is done at request of Stork and is conducted at their customer location, the production location of DSP in Delft. This project focuses on designing a Performance Measurement System that can be used at the DSP location in Delft.

I could not have completed this project without the support of some people, therefore I would like to thank some people. First, I would like to thank Niels Meerdink for giving me the opportunity to do this project at Stork and for all his positive feedback and support. Besides, I would like to thank my other colleagues of DSP and Stork for their support, information and time. In addition, I would like to thank my graduation committee, Rudy Negenborn, Wouter Beelaerts and Marcel Ludema for their feedback and good ideas during the supervision meetings. At last, I would like to thank my family and friends for their support during my graduation and the rest of my study.

Enjoy reading and whether you have any questions after reading this report, please do not hesitate to contact me.

R. van Rijn

Delft, 10 May 2017

Management summary

At the Zor-f plant in Delft DSM Sinochem Pharmaceuticals (DSP) produces 7-ADCA (7-aminodeacetoxy cephalosporanic acid). This is a semi-finished pharmaceutical product that can be used for the production of antibiotics. The production process of 7-ADCA is executed by different equipment units. These equipment units need to be maintained in order to reduce or eliminate equipment failure and consequences of equipment failure. To reduce the maintenance costs of the Zor-f plant DSP has outsourced the maintenance process of the Zor-f plant to the joint venture DSC. The maintenance process consists of the planning, scheduling and execution of maintenance activities.

At the Zor-f plant DSC and DSP use a Performance Measurement System (PMS) that monitors the condition of the maintenance process of the Zor-f plant. Besides, this system defines the incentive of the Performance Based Contract (PBC) between DSC and DSP. In a PBC the customer pays the contractor, only if the contractor has delivered the required outcome of the delivered service. Next, by using the PMS for managing the maintenance process of the Zor-f plant and the PBC between DSC and DSP three main goals can be achieved:

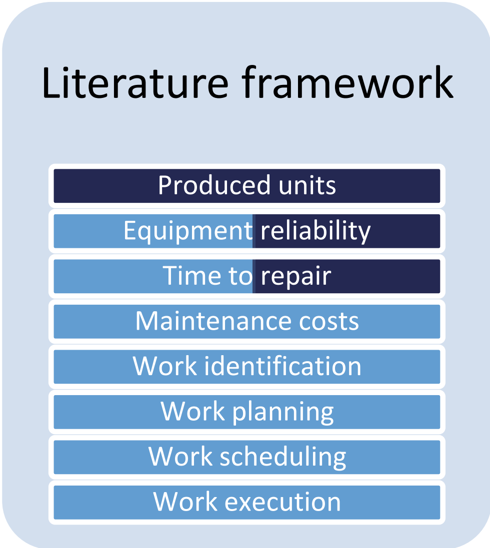
- Improvement of the maintenance process and equipment performance of the Zor-f plant
- Stimulation of DSC to carry out an effective and efficient maintenance process
- Alignment of the objectives of DSC and DSP

However, the current PMS mainly monitors maintenance costs and whether activities are carried out. Besides, the current system defines the incentive of the PBC mainly by process Performance Indicators instead of Performance Indicators that measure the outcome of the delivered service. Hence, DSC cannot carry out a flexible maintenance process. As a result of these shortcomings, the use of the current PMS for managing the maintenance process of the Zor-f plant and the PBC between DSC and DSP, does not full fill the three main goals mentioned above.

In order to solve this problem a new PMS needs to be designed. Therefore the design objective of this project is: *"To design a performance measurement system that can be used to manage the maintenance process of the Zor-f plant and the Performance Based Contract between DSC & DSP in order to improve the maintenance process & equipment performance of the Zor-f plant, to stimulate DSC to carry out an effective & efficient maintenance process and to align the objectives of DSC & DSP".* In order to achieve the design objective the main research question of this project needs to be answered: *"What characteristics need to be managed in order to improve the maintenance process & equipment performance of the Zor-f plant, to stimulate DSC to carry out an effective & efficient maintenance process and to align the objectives of DSC & DSP?"*

Literature review

In order to answer the main research question a literature review is performed. This literature review presents that regardless of the industry the outcome of a delivered service defines the incentive of a PBC. More specifically in the manufacturing industry, the outcome of the delivered service can be defined by two characteristics. These are called incentive characteristics and are: *equipment availability* and/or *produced units.* The incentive characteristic *equipment availability* is determined by equipment reliability and time to repair. The literature review also presents that several characteristics need to be measured in order to monitor the condition of a maintenance process. These are called the maintenance characteristics and are: *work identification, work planning, work scheduling*, *work execution, maintenance costs, equipment reliability* and *time to repair*. Next, the incentive and maintenance characteristics are combined in a literature framework, shown on the next page. In the figure the incentive characteristics are presented in light blue and the maintenance characteristics are presented in dark blue. The figure shows that there are two characteristics which are both an incentive characteristic as a maintenance characteristic.



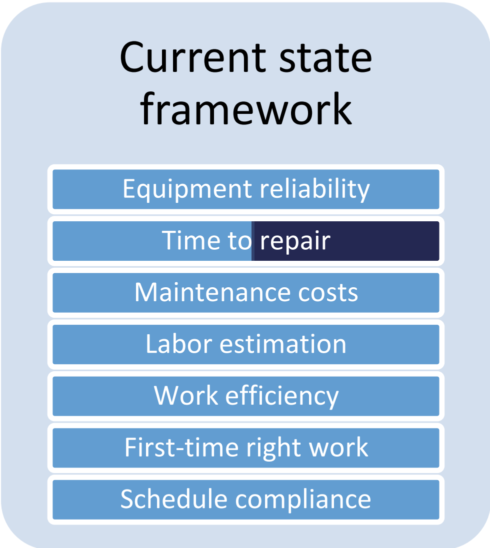
Practice: Case study at the Zor-f plant
In order to determine which party influences the incentive characteristics from literature, the maintenance process and organization structure of the Zor-f plant are analyzed. The analysis shows that mainly DSP influences the characteristic *produced units*, that both DSC as DSP influence the characteristic *equipment reliability* and that DSC influences the characteristic *time to repair*. The influence of DSP is mainly caused by the fact that DSP is responsible for the decision when maintenance activities need to be done. The influence of DSC is caused by the fact that DSC is responsible for the execution of the maintenance activities.

In order to determine how the maintenance characteristics from literature behave in practice, the maintenance process of the Zor-f plant is analyzed. This analysis shows that several maintenance characteristics are related to the maintenance objectives of the Zor-f plant. These are the five maintenance characteristics: *equipment reliability, time to repair, maintenance cost, work planning* and *work execution*. [redacted] At last, the analysis shows that the characteristic *work execution* is strongly dependent on the characteristic *work planning* at the Zor-f plant, because during *work execution* materials and third parties are used which are selected during *work planning.* In addition, the characteristics *work planning* and *work execution* have a large influence on the characteristics *equipment reliability, time to repair* and *maintenance costs* at the Zor-f plant, because *work planning* and *work execution* are together responsible for nearly all maintenance costs and are directly linked to equipment.

Design requirements and constraints
In order to provide a structure that can be used to design the new PMS requirements and constraints are formulated. Firstly, these design requirements and constraints describe which maintenance and incentive characteristics need to be measured by the PMS in order to monitor the condition of a maintenance process and to define the incentive of a PBC. Secondly, the design requirements and constraints describe how to measure these characteristics.

Design Performance Measurement System

In order to design the new PMS for the Zor-f plant the maintenance characteristics from the literature framework, the findings of the case study, the design requirements and the constraints are combined. This results in seven maintenance characteristics that need to be measured by the new PMS. These are the maintenance characteristics: *equipment reliability, time to repair, maintenance costs, labor estimation, work efficiency, first-time right work* and *schedule compliance.* The maintenance characteristics *work identification* and *work scheduling* from the literature framework are not taken into account, because they are less important than the other maintenance characteristics at the Zor-f plant. The maintenance characteristics *work planning* and *work execution* from the literature framework are split into more detailed elements. Besides, combining the incentive characteristics from the literature framework, the findings of the case study, the design requirements and the constraints, results in one incentive characteristic that needs to be measured by the new PMS. This is the incentive characteristic: *time to repair.* The other incentive characteristics from the literature framework are not taken into account, because DSP influences these characteristics. Next, the maintenance and incentive characteristics that need to be measured by the new PMS are combined in a current state framework, shown in the figure below. In the figure the incentive characteristics are presented in light blue and the maintenance characteristics are presented in dark blue.



The characteristics from the current state framework can be measured by the following Performance Indicators *Mean Time Between Failure (MTBF)*, *Mean Time To Repair (MTTR)*, *direct maintenance costs*, *labor estimation, man-power efficiency*, *rework* and *schedule compliance*. Together they create the new PMS.

Evaluation and conclusion

In order to test if the new PMS is correctly designed and if the goals set out previously are met, the new PMS is evaluated. The evaluation shows that the new PMS meets all the design requirements and constraints. This means the maintenance process of the Zor-f plant is correctly monitored and the incentive of the PBC between DSC and DSP is correctly defined by the PMS. Besides, the evaluation shows that managing the maintenance process of the Zor-f plant based on all maintenance characteristics of the current state framework has the potential to improve the maintenance process and equipment performance of the Zor-f plant. At last, the evaluation shows that managing the PBC between DSC and DSP based on the incentive characteristic of the current state framework has the potential to stimulate DSC to carry out an effective & efficient maintenance process and aligns the objectives of DSC & DSP. To conclude the new PMS is correctly designed and meets the three goals set out previously. So, the new PMS achieves the design objective of this project.

Recommendations

In order to implement this new PMS successfully at the Zor-f plant and at other plants this project does some recommendations. Firstly, from a scientific perspective it is recommended to do more case studies, in order to identify if the new PMS meets always the goals set out in this project. Besides, it is recommended for DSC and DSP to start directly with the implementation of the PMS at the Zor-f plant and at the other plants of DSP in Delft where DSC carries out the maintenance process. This is possible, because at these other plants the maintenance processes are equal to the maintenance process of the Zor-f plant. Also it is recommended for DSC and DSP to include a clear definition of the Performance Indicator *Mean Time To Repair* in the PBC. As a result of this, it is not possible to call into question the incentive of DSP. Moreover, it is recommended for DSC and DSP to do further research in order to define the incentive of the PBC by more than one Performance Indicator. This way the disadvantages of defining an incentive by one Performance Indicator are overcome. At last, it is recommended for DSC and DSP to do further research in order to define the incentive of the PBC based on more type of maintenance activities. Since, the new PMS defines only the incentive based on maintenance activities that reduce the consequence of equipment failure and it defines not the incentive based on maintenance activities that reduce equipment failure.

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List of Abbreviations

7-ADCA	*7-Aminodesacetoxy cephalosporanic acid*
CM	*Corrective Maintenance*
CO	*Correctief Onderhoud (= Corrective maintenance)*
DMAIC	*Define-Measure-Analyze-Improve-Control*
DSC	*Name of the joint venture Stork & SPIE*
DSM	*Dutch State Mines*
DSP	*DSM Sinochem Pharmaceuticals*
E&I	*Electrical & Instrumentation*
IER	*Improvement Equipment Reliability*
KPI	*Key Performance Indicator*
LMRA	*Last Minute Risk Analysis*
MTBF	*Mean Time Between Failure*
MTTR	*Mean Time To Repair*
OHC	*Onderhoudsconcept (=Maintenance concept)*
PBC	*Performance Based Contract(ing)*
PMS	*Performance Measurement System*
PI	*Performance Indicator*
PM	*Preventive Maintenance*
PO	*Preventief Onderhoud (=Preventive Maintenance)*
RAB	*Replacement Asset Base*
RCA	*Root Cause Analysis*
SAP	*Systeme, Anwendungen und Produkte = Business software*
SHE	*Safety, Health and Environment*
SRQ	*Sub Research Question*
SWOT	*Strengths, Weaknesses, Opportunities and Threats*
WO	*Work Order*
Zor-f	*Name of the 7-ADCA production plant of DSP in Delft*

1 Introduction

1.1 Project context

The joint venture DSM Sinochem Pharmaceuticals (DSP), founded in 2011, is global leader in sustainable antibiotics and antifungals (DSM Sinochem Pharmaceuticals, 2016a) (DSM Sinochem Pharmaceuticals, 2016b). DSM owns 50% of the share of the joint venture, the other 50% of the share is owned by Sinochem Pharmaceuticals. DSP has different operation locations in the world, for example in China, Egypt and Spain (DSM Sinochem Pharmaceuticals, 2016b). In Delft DSP has three (production) plants. The largest plant in Delft is the Zor-f plant, where DSP has produced 7-ADCA (7-aminodeacetoxy cephalosporanic acid) since 2001.

7-ADCA is a semi-finished pharmaceutical product that can be used for the production of antibiotics. Therefore, DSP participates in the global antibiotics market. The last few years this market has been characterized by a growth of Chinese manufactures and a decrease in the price of antibiotics (Tyrone, Simpson, & Dehlin, 2012). [redacted] The customers of the Zor-f plant are both internal customers as external customers of the DSP network. 7-ADCA is a white powder stored in bags of one cubic meter before it is transported to the customer. A by-product of the production process of 7-ADCA is a kind of lime. This by-product can be used as fertilizer in the agriculture. Local farmers can pick up the lime at the Zor-f plant for free.

The Zor-f plant has a progressive production process compared to other plants which produce 7-ADCA, because of the following four reasons (Tyrone, Simpson, & Dehlin, 2012). Firstly, at the Zor-f plant the production process consists of fewer steps. Secondly, at the Zor-f plant the production process produces little by-products. Thirdly, at the Zor-f plant the production process uses less toxic materials. At last, the production process of the Zor-f plant operates at lower temperatures.

[redacted]

[redacted]

Figure 1; Production process and equipment units of the Zor-f plant

The performance of equipment is called, equipment capability. The equipment capability can be determined in different ways, for example by the capacity, the quality or the responsiveness of equipment (Tsang, Jardine, & Kolodny, 1999). In order to optimize the capability of the equipment of the Zor-f plant, maintenance needs to be done at the Zor-f plant (Tsang, Jardine, & Kolodny, 1999). The Maintenance Engineering Society of Australia defines maintenance as taking engineering decisions and doing associated actions which are necessary and sufficient for the optimization of the capability of equipment (Maintenance Engineering Society of Australia (MESA), 1995).

In order to understand what maintenance means at the Zor-f plant the maintenance of four equipment units is described below. [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Figure 2; Control valve, polari meter, impeller pump and rotary spray head

In order to reduce the maintenance costs of the Zor-f plant, DSP has outsourced the associated actions of maintenance to a third party since 2001. This means that DSP has outsourced the work planning, work scheduling and work execution of maintenance activities to a third party. The combination of work planning, scheduling and execution of maintenance activities is called the maintenance process in this report. The third party whom executes currently the maintenance process for DSP, is the joint venture DSC. The joint venture DSC was specifically founded for DSP. Stork owns 50% of the share of the joint venture, the other 50% of the share is owned by SPIE. Maintenance activities regarding mechanical engineering are performed by Stork and maintenance activities regarding Electrical & Instrumentation (E&I) are performed by SPIE.

1.2 Description current state

Currently, at the Zor-f plant a Performance Measurement System (PMS) is used. This is a structured list of Performance Indicators that measures different characteristics (Pintelon & Puyvelde, 1997). In this section is firstly explained why a PMS is used at the Zor-f plant. Next, the current PMS of the Zor-f plant is described.

First, a PMS is used at the Zor-f plant in order to achieve the four objectives presented in the blue circles of Figure 3 at the left side. A PMS is used at the Zor-f plant in order to monitor the condition of the maintenance process of the Zor-f plant. In this project 'the condition of the maintenance process' is defined as the current state of the maintenance process with regard to its quality at a specific time. It is important to monitor the condition of the maintenance process of the Zor-f plant, because it provides insight in the condition of maintenance process and detects problems in the maintenance process (Arts, Knapp, & Mann, 1998). Next, based on this information the maintenance process of the Zor-f plant can be managed. By managing the maintenance process, the maintenance process can be improved (Arts, Knapp, & Mann, 1998). Improvement of the maintenance process is important for the Zor-f plant, because the current maintenance process does not perform well. The current maintenance process is not effective, because a lot of maintenance activities are not executed the first time right (Appendix A, [redacted]). In addition, the process is inefficient, because the execution of the maintenance activities results in higher costs than needed and takes more time than needed (Appendix A, [redacted]). Finally, improvement of the maintenance process can contribute to improvement of the equipment performance of the Zor-f plant, because if the maintenance process is improved as a result equipment failure and consequences of equipment failure can be reduced. Improvement of equipment performance is important for the Zor-f plant, because it results in more produced products. So, finally more profit for DSP.

Second, a PMS is used at the Zor-f plant in order to achieve the three objectives presented in the blue circles of Figure 3 at the right side. A PMS is used at the Zor-f plant in order to define the incentive of the Performance Based Contract (PBC) Between DSC and DSP. By defining the incentive of the PBC between DSC and DSP, the PBC can be managed. Next, by managing the PBC DSC can be stimulated to carry out an effective and efficient maintenance process. For DSP and DSC this is important, because this results in lower costs for both parties (NG, Maull, & Yip, 2009). In addition, by managing the PBC the objectives of DSC and DSP can be aligned (Appendix A, [redacted]). For DSP this is important, because this way DSC contributes to the objectives of DSP.

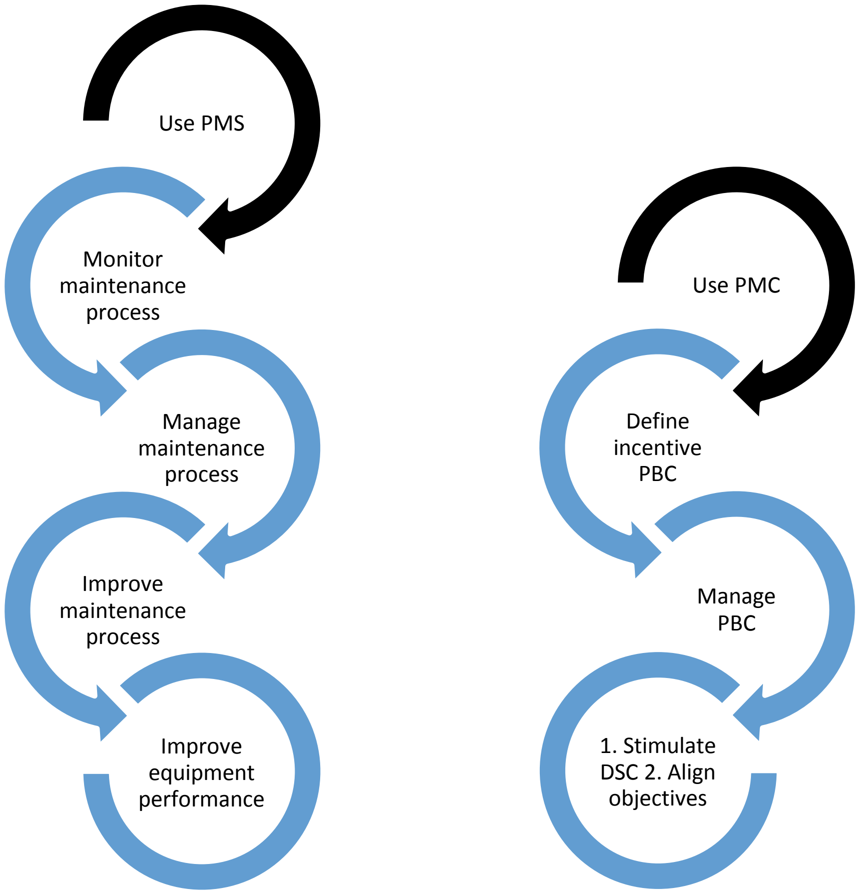

Figure 3; Reasons for using a Performance Measurement System at the Zor-f plant

The current PMS has been used since January 2016. The current PMS consists of eight Performance Indicators, discussed below.

- **Availability Zor-f plant [%]**
  This Performance Indicator measures the availability of the entire Zor-f plant. The Performance Indicator is calculated by the amount of 7-ADCA produced under ideal conditions minus the amount of 7-ADCA lost by maintenance activities and equipment failure, divided by the amount 7-ADCA produced under ideal conditions. This means that currently the availability of the Zor-f plant is defined by the amount of produced product and is not defined at equipment level ([redacted], Appendix A).

- **Top 5 performance killers provided with Root Cause Analysis [%]**
  This Performance Indicator measures whether an activity is carried out, in this case whether performance killers in the top 5 are provided with a Root Cause Analysis. Performance killers are events that have a negative effect on production. The top 5 performance killers is established each quarter. A root cause analysis is done in order to determine the cause of a performance killer ([redacted], Appendix A).

- **Actual costs versus budget [%]**
  This Performance Indicator measures the actual maintenance costs compared to the planned maintenance costs of all maintenance activities at the Zor-f plant ([redacted], Appendix A).

- **Replacement asset base value [%]**
  This Performance Indicator measures the total actual maintenance costs compared to the total invested costs of the maintained equipment at the Zor-f plant ([redacted], Appendix A).

- **Top 5 cost drivers provided with Root Cause Analysis [%]**
  This Performance Indicator measures whether an activity is carried out, in this case whether cost drivers in the top 5 are provided with a Root Cause Analysis. Cost drivers are events which are responsible for high costs. The top 5 cost drivers is established each quarter. A root cause analysis is done in order to determine the cause of a cost driver ([redacted], Appendix A).

- **Backlog work orders [#]**
  This Performance Indicator measures the amount of maintenance activities that is not executed in its scheduled time window.

- **Compliance tasks carried out on time [%]**
  This Performance Indicator measures the percentage of compliance tasks that is executed in its scheduled time window. Compliance tasks are required tasks that need to be done before a specific date in order to reduce the risks related to these tasks.

- **Hands on Tool Time measurement performed [yes/no]**
  This Performance Indicator measures whether an activity is carried out, in this case whether a Hands on Tool Time measurement is performed. A Hands on Tool Time measurement shows the efficiency of the execution of maintenance activities.

Currently, all Performance Indicators of the PMS are used to monitor the condition of the maintenance process of the Zor-f plant. Besides, currently all Performance Indicators of PMS are used to define the incentive of the PBC between DSC and DSP. If the target of all Performance Indicators of the PMS are achieved [redacted] If the targets of not all Performance Indicators are achieved, the incentive will decrease incrementally. The incentive for DSC is defined each quarter.

1.3 Problem definition

Three main problems can be identified for the current PMS. First, the current PMS defines the incentive of the PBC between DSC and DSP by all Performance Indicators of the current PMS. This means that the incentive of the PBC is mainly defined by process Performance Indicators and is hardly defined by Performance Indicators that measure the outcome of the maintenance process. For this reason DSC cannot carry out a flexible maintenance process, if they also want a large incentive. As a result of this, DSC cannot always carry out the maintenance process in the most effective and efficient way. To conclude, the current PMS is not correctly designed in order to stimulate DSC to carry out an effective and efficient maintenance process.

Secondly, DSC wants to perform well on the Performance Indicators of the PMS in order to receive a large incentive. DSP wants a high availability of the Zor-f plant, so a good outcome of the maintenance process. Due to the fact that the current PMS defines mainly the incentive of the PBC by process Performance Indicators, DSC is mainly focusing on the maintenance process itself and is not focusing on the outcome of the maintenance process. As a result of this, DSC and DSP have not the same objectives. To conclude, the current PMS is not correctly designed in order to align the objectives of DSC and DSP.

Thirdly, the Performance Indicators of the current PMS measure mostly whether activities are carried out. In addition, the current PMS mainly focusses on the maintenance costs. As a result the current PMS does not monitor the condition of the maintenance process of the Zor-f plant well, because it provides little insight in the condition of the maintenance process and does not detect the problems in the maintenance process. For this reason, the maintenance process cannot be managed well. Due to this, the maintenance process and equipment performance of the Zor-f plant cannot be improved. To conclude, the current PMS is not correctly designed in order to improve the maintenance process and equipment performance of the Zor-f plant.

These three problems can be summarized in the following problem definition:

"The current performance measurement system is not correctly designed in order to stimulate DSC to carry out an effective & efficient maintenance process, to align the objectives of DSC & DSP and to improve the maintenance process & equipment performance of the Zor-f plant".

The problem definition contains two knowledge gaps. The first knowledge gap is caused by the lack of knowledge of what needs to be measured by the PMS in order to define the incentive of the PBC between DSC and DSP. The second knowledge gap is caused by the lack of knowledge of what needs to be measured by the PMS in order to monitor the condition of the maintenance process at the Zor-f plant.

1.4 Project scope

This project focusses on monitoring the condition of a maintenance process in the pharmaceutical manufacturing industry. Therefore a case-study is done at the Zor-f plant of DSP in Delft, because the Zor-f plant has significant more maintenance activities than the other plants of DSP in Delft (Appendix A, [redacted]). This project focusses on the maintenance processes for preventive, predictive and corrective maintenance activities. These are repair, replacement, calibration, inspection, cleaning and lubrication activities. In chapter 3 and 4 this is discussed in more detail. This project will not attempt to improve the current maintenance process and equipment performance of the Zor-f plant. So, the current maintenance process and equipment performance of the Zor-f plant are considered as a fact in this project.

In this project the focus is only on the incentive of the PBC between DSC and DSP. This project will therefore not attempt to adapt other aspects of the PBC, such as the responsibilities, the terms and conditions, the assignment, etc. These things are considered as a fact in this project.

At last, this project focusses on designing a PMS. In this project the focus is only on what needs to be measured by the PMS and how to measure this, so which Performance Indicators can be used. This project will not attempt to provide a weight to the Performance Indicators. Moreover, this project will not attempt to define whether the measured performance by the PMS are good or bad. At last, this project will not design the lay out of the PMS.

1.5 Design objective & research question

Based on the problem definition and the scope of this project the design objective is formulated.

"To design a performance measurement system that can be used to manage the maintenance process of the Zor-f plant and the Performance Based Contract between DSC & DSP in order to improve the maintenance process & equipment performance of the Zor-f plant, to stimulate DSC to carry out an effective & efficient maintenance process and to align the objectives of DSC & DSP".

In the design objective 'an effective maintenance process' is defined as a maintenance process that executes the right things and executes these things in the right way, in order to increase the uptime of equipment. In addition, 'an efficient maintenance process' is defined as a maintenance process that increases the uptime of equipment, with minimal effort, so with minimal time and costs.

This project will be performed from the viewpoint of DSC and DSP, since the design objective of this project is related to both parties. The maintenance process that can be improved is mainly interested from the viewpoint of DSC. The equipment performance that can be improved and the objectives of DSC & DSP that can be aligned are mainly interested from the viewpoint of DSP. At last, the maintenance process that can be carried out more effective and more efficient by DSC is interested from the viewpoint of DSP and DSC. This means that the recommendations given in the end of this report are both for DSC as for DSP.

In order to achieve the design objective of this project, the main research question of this project will be answered first. The main research question is based on the problem definition and the knowledge gaps. By answering the main research question these knowledge gaps will be covered. Below the main research question of this project is formulated.

"What characteristics need to be managed in order to improve the maintenance process & equipment performance of the Zor-f plant, to stimulate DSC to carry out an effective & efficient maintenance process and to align the objectives of DSC & DSP?"

In order to answer the main research question, the ten sub research questions (RSQ) as described below will be answered. In Chapter 2 is explained how these sub research questions will be answered.

- SRQ 1: *Which characteristics can define the incentive of a Performance Based Contract in the manufacturing industry according to literature?*
- RSQ 2: *Which characteristics need to be measured, in order to monitor the condition of a maintenance process according to literature?*
- RSQ 3: *What and who has influence in practice on the characteristics from literature that can define an incentive of a Performance Based Contract?*
- RSQ 4*: How do the characteristics from literature that needs to be measured in order to monitor the condition of a maintenance process behave in practice?*

- RSQ 5: *Which characteristics need to be measured in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the Performance Based Contact between DSC and DSP?*

- RSQ 6: *Which Performance Indicators need to be used in order to measure the identified characteristics?*

- RSQ 7*: Who needs to manage the selected Performance Indicators?*

- RSQ 8: *Has, using the performance measurement system for managing the maintenance process of the Zor-f plant, the potential to improve the maintenance process and equipment performance of the Zor-f plant?*

- RSQ 9: *Has, using the performance measurement system for managing the Performance Based Contract between DSC and DSP, the potential to stimulate DSC to carry out an effective and efficient maintenance process?*

- RSQ 10: *If the performance measurement system is used to manage the Performance Based Contract between DSC and DSP, are the objectives of DSC and DSP aligned?*

Based on the problem definition is decided to do a 'greenfield project'. This means that in this project the current PMS is not improved based on the knowledge obtained during this project, but that an entire new PMS is designed.

1.6 Relevance of the project

The relevance of this project is both scientific as practical. From a scientific perspective this project is relevant, because the current literature on PBCs in the manufacturing industry is focusing on the delivered maintenance service consisting of taking engineering decisions and doing associated actions. However, there is little or no literature on PBCs in the manufacturing industry focusing on the delivered maintenance service consisting of only the associated actions, so only the maintenance process. If only the maintenance process is outsourced by a PBC, the relation between the customer and the contractor is different than if engineering decisions and associated actions are outsourced by a PBC. As a result of this, it can be possible that the incentive of the PBC needs to be defined in another way than if engineering decisions and associated actions are outsourced by a PBC. This project will research this and will therefore bridge the knowledge gap regarding what defines the incentive of a PBC if only the maintenance process is outsourced by a PBC. Hence, this project will contribute to the scientific literature.

From a practical perspective this project is relevant for both DSC as DSP, because the new PMS designed in this project can replace the current PMS. For DSC this will result in an improved maintenance process. For DSP this will result in improved equipment performance. Besides, DSP will profit from the alignment of their objectives with the objectives of DSC. Since, this way DSC contributes to DSP's objectives. At last, DSC and DSP will profit from the fact that DSC will be stimulated to carry out an effective and efficient maintenance process. Since, it will reduce the costs for DSC and DSP. Due to the large benefits of this project for both DSP as DSC, this project has a high relevance for both parties.

1.7 Report structure

The structure of this report is based on the design methodology of this project. The design methodology used in this project is a combination of the prescriptive engineering process design models of Jones & Thornely (1962), Krick (1969) and Cross (2000). Combining several stages of these three models results in a design process consisting of five stages, a problem formulation, an analysis, a setting requirement, a synthesis and an evaluation stage. The design methodology used in this project and the related stages are discussed in more detail in the next chapter, Chapter 2. In Figure 4 the chapters of this report are linked to the five stages mentioned above. Besides, the figure shows which sub research questions are answered in each chapter.

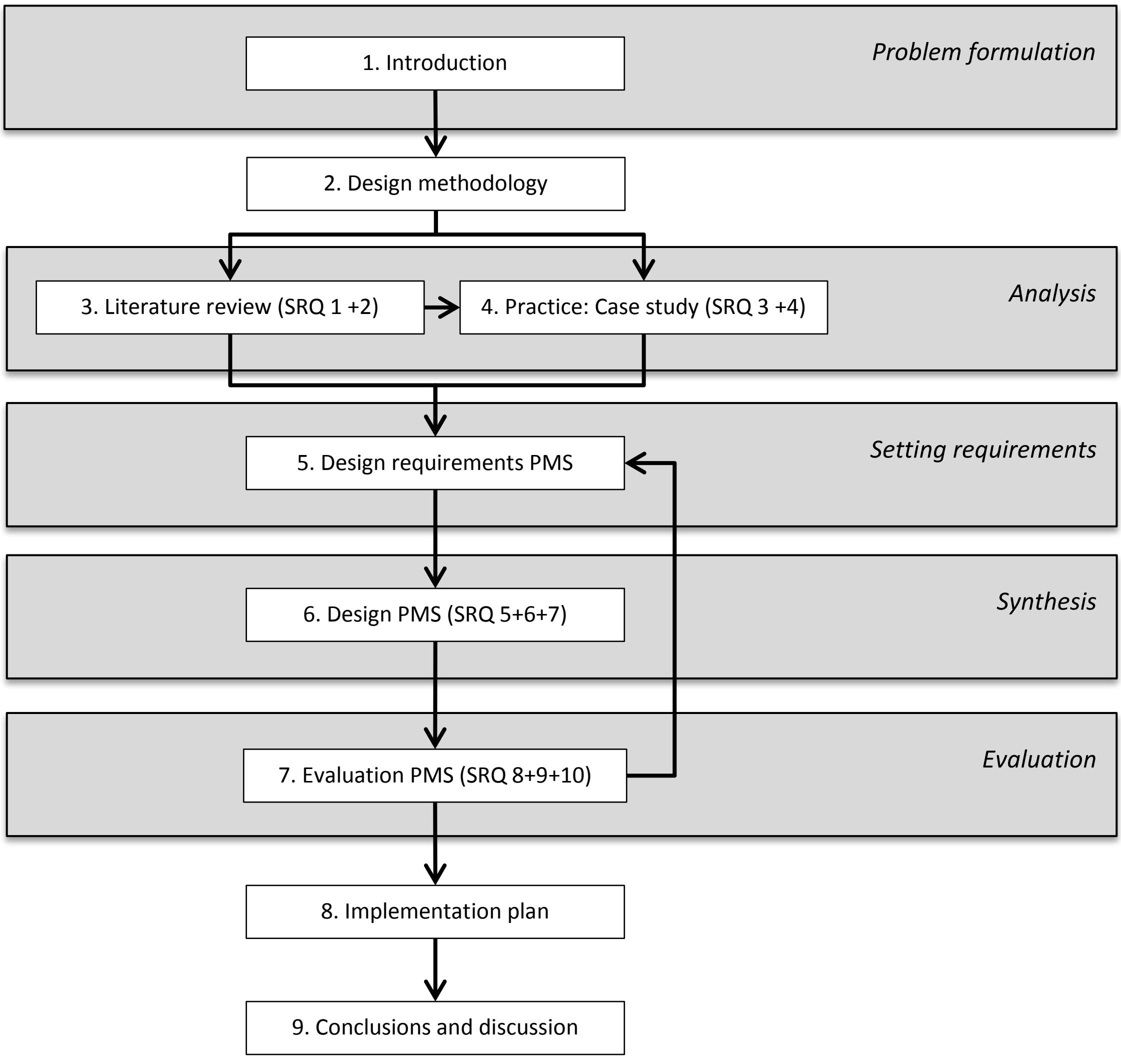

Figure 4; Report structure

2 Design methodology

This chapter presents the design methodology used in this project to achieve the design objective mentioned in section 1.5 of this report. The chapter starts with the generation of a design process model for this project. Next, each stage of the generated design process model is discussed in more detail.

2.1 Design process model

In the (scientific) literature there is a lack of a methodological approach to design a Performance Measurement System (PMS) (Muchiri, Martin, Pintelon, & Gelders, 2011). Therefore, it is not possible to use an existing design methodology for this project and is it required to generate a new design methodology for this project.

The problems identified in section 1.3 can be solved by manufacturing a new PMS. A design methodology that focusses on solving a problem by creating a solution that can be manufactured, is the design engineering methodology (Evbuomwan, Sivaloganathan, & Jebb, 1996). Therefore, the design methodology generated in this project is based on the design engineering methodology.

The design engineering methodology has two main classes of models that describes the design process (Evbuomwan, Sivaloganathan, & Jebb, 1996). The first class consists of prescriptive models. These models emphasize the need for analytical work prior to the generation of a solution (Cross, 2000). Hence, the problem that needs to be solved is fully understood and the real problem is identified, before solutions are generated (Cross, 2000). The second class consists of descriptive models. These models generate a solution concept early in the design process (Cross, 2000). Next, the solution concept is analyzed, evaluated, refined and developed (Cross, 2000).

Before a PMS is designed, it is needed to know what needs to be measured by the PMS (Stork technical services, 2016). In order to identify what needs to be measured by the PMS, analyses are needed. Prescriptive models emphasize the need for analytical work. For this reason, the design methodology generated in this project is a combination of prescriptive models.

There are no existing prescriptive models that have the same design process stages as the design process stages required for this project. Therefore, a simple prescriptive model is used as starting point. Next, this model is adapted, in order to obtain a design process model that describes the design process steps required for this project. The prescriptive model used as starting point is the prescriptive model developed by Jones & Thornley (1962). This model consists of three stages the analysis, synthesis and evaluation stage (Jones & Thornley, 1962). The analysis stage analyzes the factors related to the problem or/and its solution. Besides, in the analysis stage the design requirements are formulated. Next, in the synthesis stage solutions are generated. At last, in the evaluation stage the generated solutions are evaluated.

However, the model of Jones & Thornley (1962) has some shortcomings. Firstly, the model does not focus on the problem that is solved by the generated solutions. This can have major consequences, because if a problem is not well defined, it is also not possible to design the right solutions for the problem. Besides, the model does not focus on the formulation of the design requirements. While, the design requirements are important in the evaluation stage.

In order to overcome the shortcoming of the model of Jones & Thornley (1962), stages of other models are added to the stages of the model of Jones & Thornely (1962). These are stages of the model of Krick (1969) and the model of Cross (2000). The model of Krick (1969) defines the design process by five stages the problem formulation, problem analysis, research, decision and specification stage. The model of Cross (2000) defines the design process by six stages, clarification of objectives, establish functions, setting requirements, generating alternatives, evaluating alternatives and improve details. So, in order to overcome the shortcoming of the model of Jones & Thornely (1962) the problem formulation stage of the model of Krick (1969) and the setting requirements stage of the model of Cross (2000) are added to the stages of the model of Jones & Thornley (1962).

By combining the selected stages of the models of Jones & Thornely (1962), Krick (1969) and Cross (2000) the required design process model for this project is obtained. Shown in Figure 5. The design process starts with the problem formulation stage. In this stage the design problem that needs to be solved is clearly defined. The second stage is the analysis stage. In this stage the factors related to the problem and/or its solutions are analyzed. The third stage is the setting requirement stage. In this stage the required performance of the design solutions are specified. The fourth stage is the synthesis stage. In this stage the solutions are generated and the partial solutions are combined. The last stage is the evaluation stage. In this stage the solutions are evaluated based on the requirements formulated in the setting requirement stage. In the next sections all the five stages are discussed in more detail.

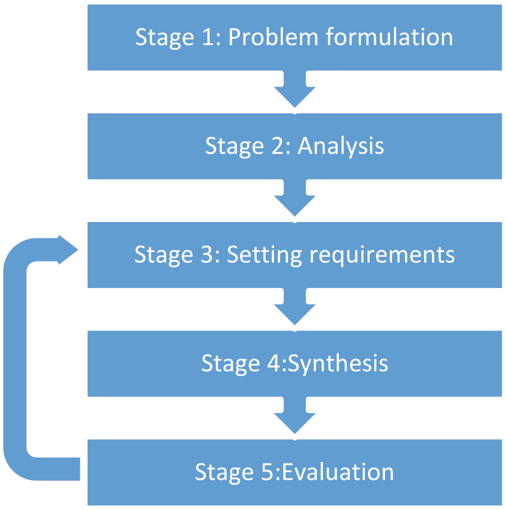

Figure 5; Design process model based on Jones & Thornely (1962), Krick (1969) and Cross (2000)

2.2 Stage 1: Problem formulation

In this stage the problem that needs to be solved is defined. Besides is identified for whom it is a problem and why it is important that the problem is solved. In order to define the problem that needs to be solved by this project interviews are done with the plant manager, maintenance manager, maintenance supervisor, maintenance engineers and technicians of the Zor-f plant. See Figure 11, for their position in the organization of the Zor-f plant.

2.3 Stage 2: Analysis

The goal of the analysis stage in this project is to obtain more information about what needs to be measured by the PMS, in order to monitor the condition of a maintenance process and to define the incentive of a Performance Based Contract (PBC).

In order to answer the first two research questions *"Which characteristics can define the incentive of a Performance Based Contract in the manufacturing industry according to literature?"* and *"Which characteristics need to be measured, in order to monitor the condition of a maintenance process according to literature?"* a literature review is performed. In Chapter 3 is explained how this literature review is constructed. The identified characteristics from literature that needs to be measured in order to monitor the condition of a maintenance process and to define the incentive of a PBC, are presented in a literature framework. This framework is customized for the Zor-f plant in the synthesis stage of the design process.

Next, in order to answer the third and fourth research question *"What and who has influence in practice on the characteristics from literature that can define an incentive of a Performance Based Contract?"* and "*How do, the characteristics from literature that needs to be measured in order to monitor the condition of a maintenance process, behave in practice?"* a case study is performed at the Zor-f plant. The information used to analyze the case study is obtained by interviews with different people in the organization of the Zor-f plant, by observations done during the execution of the maintenance process and by consulting internal documents. In section 4.1 is explained which tools are further used to analyze the case study.

2.4 Stage 3: Setting requirements

Next, the required performances for the PMS are specified. Before this is done, the architecture of the PMS is defined. Next, requirements and constraints are related to the architecture of the PMS. The design requirements and constraints are formulated, based on information from (scientific) literature, interviews with different people in the organization of the Zor-f plant, interviews with a KPI expert of Stork, internal documents regarding performance measurement used by consultants of Stork, etc. After the requirements and constraints are formulated by the researcher of this project, the requirements and constraints are approved by the maintenance manager and the maintenance supervisor of the Zor-f plant.

2.5 Stage 4: Synthesis

In this stage the PMS that solves the defined problem of the problem formulation stage is generated. To generate this PMS the three steps mentioned below need to be performed.

- First, the fifth sub research question needs to be answered, "*Which characteristics need to be measured in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the Performance Based Contact between DSC and DSP*?". In order to answer this research question the characteristics from the literature framework from the analysis stage, are used as starting point. Next, based on the findings of the case-study from the analysis stage and the design requirements and constraints from the setting requirements stage is decided which characteristics are relevant for the Zor-f plant. Due to the fact that the design requirements and constraints are strict, there is one combination possible of characteristics that need to be measured. Finally, the characteristics that need to be measured in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the PBC between DSC and DSP, are presented in a current state framework.

- Next, the sixth sub research question needs to be answered, "*Which Performance Indicators need to be used in order to measure the identified characteristics?"* To the characteristics that need to be measured by the PMS, Performance Indicators are assigned. This is done based on the design requirements and constraints from the setting requirements stage and the papers of Weber & Thomas (2005) and Muchiri, Pintelon, Gelders, & Martin (2011). Since, the identified characteristics are very detailed, the characteristics can be measured by one specific Performance Indicator.

- At last, the seventh sub research question needs to be answered, "*Who needs to manage the selected Performance Indicators?"* First, the maintenance organization is divided into different levels. Next, the selected Performance Indicators are assigned to a level. As a result the Performance Indicators are automatically assigned to a party who needs to manage the Performance Indicator. Each Performance Indicator can be assigned to one specific level of the maintenance organization and therefore can be also assigned to one specific party who needs to manage the Performance Indicator.

Finally, by combining all the findings done during this stage a PMS is designed. Due to the fact that there is one combination of characteristics that need to be measured, each characteristic is measured by one Performance Indicator and each Performance Indicator is managed by one party, there is also designed one PMS in this project.

2.6 Stage 5: Evaluation

In this stage the generated solution of the previous stage, the PMS, is evaluated. This evaluation consists of three parts. The first part focusses on if the PMS is correctly designed. The second and third part focus on if the use of the PMS results in the intended behavior.

- The first part evaluates if the PMS is correctly designed, in order to monitor the condition of the maintenance process of the Zor-f plant and in order to define the incentive of the PBC between DSC and DSP. So, if the PMS meets the requirements and constraints formulated during the setting requirements stage. First, the researcher of this project has established if the requirements and constraints are met or are not met by the PMS. Next, the maintenance supervisor and plant manager of the Zor-f plant have approved the decisions of the researcher. How this is done exactly, is explained in more detail in section 7.1.

- The second part evaluates if using the PMS for managing the maintenance process, has the potential to improve the maintenance process and the equipment performance of the Zor-f plant. Therefore this part of the evaluation answers the eight sub research question, *"Has, using the performance measurement system for managing the maintenance process of the Zor-f plant, the potential to improve the maintenance process and equipment performance of the Zor-f plant?"* This part of the evaluation is performed by using the DMAIC (Define-Improve-Analyze-Improve-Control) method. This method is used, because it can quantify the potential improvement of the maintenance process and the equipment performance. How this is done exactly, is explained in section 7.2.

- The third part evaluates if using the PMS for managing the PBC, has the potential to stimulate DSC to carry out an effective and efficient maintenance process. Besides, this part evaluates if using the PMS for managing the PBC, aligns the objectives of DSC and DSP. Therefore this part of the evaluation answers the ninth and tenth sub research question, "*Has, using the performance measurement system for managing the Performance Based Contract between DSC and DSP, the potential to stimulate DSC to carry out an effective and efficient maintenance process?"* and "*If the performance measurement system is used to manage the Performance Based Contract between DSC and DSP, are the objectives of DSC and DSP aligned?"* This part of the evaluation is performed by doing a SWOT-analysis. A SWOT-analysis is an often used method to show Strengths, Weaknesses, Opportunities and Threats of an organization (managementmodellensite.nl, n.d.). There is chosen to perform this evaluation by doing a SWOT-analysis, because it is a simple tool that guides evaluations and can be understood by everyone. The SWOT-analysis is done by the plant manager, the responsible person for the PBC from the side of DSP, and the SWOT-analysis is done by the person who is responsible for the PBC from the side of DSC. In section 7.3 is explained in more detail how this is done.

3 Literature review

This chapter presents what defines the incentive of a Performance Based Contract (PBC) according literature. Besides, this chapter presents what needs to be measured in order to monitor the condition of a maintenance process according literature. Next, the identified characteristics that define the incentive of a PBC and the identified characteristics that need to be measured in order to monitor the condition of a maintenance process, are combined in a literature framework. This literature framework is used as starting point for the new Performance Measurement System (PMS) designed in this project. The chapter ends with sub conclusions that answer the two sub research questions: "*Which characteristics can define the incentive of a Performance Based Contract in the manufacturing industry according to literature?*" and *"Which characteristics need to be measured, in order to monitor the condition of a maintenance process, according to literature?"*

3.1 Performance Based Contracting

The contractor's incentive in a PBC is always defined by the outcome of the delivered service (NG, Maull, & Yip, 2009). What is considered as the outcome of the delivered service depends on the used incentive model and the industry. This section identifies different incentive models for PBCs in the manufacturing industry. In addition this section gives an example of the application of an incentive model in the manufacturing industry in practice.

In order to find papers on the basic principles of PBCs in the scientific literature the key words *Performance-based contracts, Outcome-based contracts* and *Performance Contracting* are used. Next, in order to find existing incentive models for PBCs in the manufacturing industry the key words *Payment model* and *Manufacturing industry* are added to the key words mentioned above. This results in a paper of Hypko, Tilebein & Gleich (2010a) that discusses different incentive models in the manufacturing industry. In order to give an example of an incentive model in the manufacturing in practice, the concept Power-by-the-hour of Roll Royce is shortly discussed. This is one of the most successful applications of a PBC and is also one of the most well-known applications of a PBC.

3.1.1 Description Performance Based Contracting

Before the incentive models for PBCs in the manufacturing industry are discussed, the basic principles of PBCs are shortly explained. A Performance Based Contract (PBC), also referred to as a performance contract or an outcome-based contract (Hypko, Tilebein, & Gleich, 2010b), is a contract where the customer pays the contractor only if the contractor has delivered the required outcome of the delivered service (NG, Maull, & Yip, 2009). This means that a PBC only specifies the outcome of the delivered service. So, a PBC does not define how the contractor needs to achieve the required outcome (Behn & Kant, 1999). This gives the contractor flexibility to determine the best way to achieve the required outcome (Behn & Kant, 1999), because there is not one best way to achieve a required outcome at all times and under all circumstances (Behn & Kant, 1999).

PBCs have two main advantages. Firstly, a PBC is cost efficiency both for the customer as the contractor. Secondly, the objectives of the customer and the contractor are more aligned (NG, Maull, & Yip, 2009). This makes Performance Based Contracts attractive.

3.1.2 Incentive models for Performance Based Contracts in the manufacturing industry

In the manufacturing industry a manufacturer can outsource three types of services to a contractor, these are ownership of equipment, maintenance of equipment, operation of equipment or a combination of these three types of services (Hypko, Tilebein, & Gleich, 2010b). For all the three types of services the outcome is the same (Hypko, Tilebein, & Gleich, 2010a). Therefore the incentive models for PBCs in the manufacturing industry can be used for all the three types of delivered services.

Two incentive models for PBCs are frequently used in the manufacturing industry. The first model is the pay-on-availability model. In this model the incentive is defined by the availability of the equipment. This means the incentive is independent of the actual utilization of the equipment. In this case the customer pays for the performance delivered by the contractor (Hypko, Tilebein, & Gleich, 2010a).

The second model is the pay-per-units model, also referred to as pay-on-production model in literature. If this model is used the customer pays only for the actually demanded performance (Hypko, Tilebein, & Gleich, 2010a). This means the incentive is dependent of the actual utilization of the equipment by the customer. So, dependent on the used incentive model the incentive of a PBC in the manufacturing industry is defined by the availability of equipment or by the produced units by the equipment.

3.1.3 The concept Power-by-the-Hour

Firstly PBCs were used in the health care industry, but now a day PBCs are also used in the manufacturing industry. Mainly, the manufacturers in the defense and aerospace industry use PBCs (Hypko, Tilebein, & Gleich, 2010b). This sub section gives an example of a PBC in the aerospace industry.

Roll-Royce is a large company that manufactures engines for aircrafts and that delivers maintenance service for these engines. Roll-Royce was one of the first companies who introduced PBCs in the manufacturing industry. They introduced a PBC by the concept Power-by-the-Hour. By this concept the customers of Roll-Royce did pay based on engine availability, instead of the labor costs and material costs.

An example of a PBC of Roll-Royce based on the concept Power-by-the-Hour is the contract between Roll-Royce and the US navy. In this contract Roll-Royce was the sole provider of maintenance and logistic support for the Rolls-Royce Turbomeca F405 Adour engines, that powered the fleet of the US navy (Smith, 2013). The maintenance and logistics support consisted of maintenance, trouble-shooting and parts supply of all engines on three locations of the US navy. The US navy paid Roll-Royce based on the ready-for-issue engine availability. What is the time an aircraft is available minus the time an aircraft is out of action (Smith, 2013).

Before the PBC was used the ready-for-issue engine availability was 70%. The PBC guaranteed to the US navy a ready-for-issue engine availability of 80%. Finally, by using the PBC a ready-for-issue engine availability of 85% was achieved (Smith, 2013). In addition to the increase in ready-for-issue engine availability, the PBC had also three other advantages. Firstly, the US navy avoided uncertainty regarding breakdown and repair costs. Secondly, the maintenance service was improved. Thirdly, the maintenance service was provided with lower costs (Smith, 2013). This example shows the benefits of a PBC in the manufacturing industry in practice.

3.1.4 Sub conclusion Performance Based Contracting

Literature on PBCs shows that the incentive of a PBC is defined by the outcome of the delivered service. The outcome of the delivered service in the manufacturing industry is *the availability of equipment* and/or *the produced units by the equipment*. The example of the PBC between Roll-Royce and the US navy shows the success of a PBC in practice that defines the outcome of the delivered service by the availability of equipment. It should be noted that Rolls-Royce was the sole provider in this case and that in addition to maintenance Roll-Royce also delivered the logistic support related to maintenance to the US navy.

3.2 Maintenance process

A conceptual performance measurement framework describes what will and what will be not measured, in order to define performance of something (Parida, Kumar, Galar, & Stenström, 2015). This section identifies and analyzes existing conceptual performance measurement frameworks that describe what needs to be measured, in order to monitor the condition of a maintenances process.

In order to find existing conceptual performance measurement frameworks, papers are selected by using the key words *Framework/System, Maintenance, Performance measurement* and *Maintenance management*. Next, from the selected papers only the papers are used that discuss what needs to be measured in order to monitor the condition of a maintenance process in the same context and with the same scope as this project. Finally, one paper is found that corresponds to the context and scope of this project. This is the paper of Muchiri, Pintelon, Gelders and Martin (2011). This paper is relevant for this project, because it focusses on only the maintenance process. Besides, it discusses the maintenance process in the manufacturing industry. At last, it discusses the maintenance process for preventive, predictive and corrective maintenance activities. Before the conceptual performance measurement framework of Muchiri, Pintelon, Gelders and Martin (2011) is discussed, the maintenance process that is executed in the manufacturing industry is shortly explained.

3.2.1 Description maintenance process

The maintenance process is derived from the maintenance strategy, the maintenance strategy is derived from the maintenance objectives, the maintenance objectives are derived from the manufacturing policy and the manufacturing policy is derived from the corporate strategy (Muchiri, Martin, Pintelon, & Gelders, 2011). This is shown in Figure 6. As a result the maintenance process is directly influenced by the maintenance strategy and is indirectly influenced by the maintenance objectives, the manufacturing policy and the corporate strategy. Below the maintenance objectives, the maintenance strategy and the maintenance process are discussed in more detail.

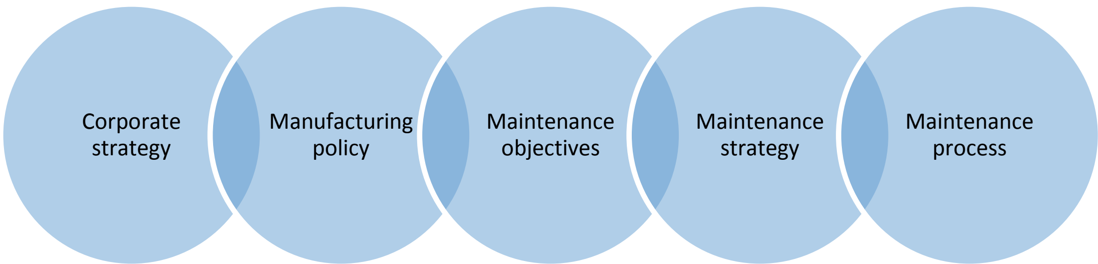

Figure 6; Derivation of the maintenance process (Muchiri, Martin, Pintelon, & Gelders, 2011)

The maintenance objectives define the required result of the maintenance process. They are indirectly derived from the company strategy and are directly derived from the manufacturing policies (Muchiri, Martin, Pintelon, & Gelders, 2011). According to Muchiri, Pintelon, Gelders and Martin (2011) the maintenance objectives of the most manufacturing plants can be summarize in five main objectives, mentioned below.

1. Ensuring plant functionality, for example availability, reliability, product quality
2. Ensuring the plant achieves its design life
3. Ensuring plant safety and environment
4. Ensuring cost effectiveness in maintenance
5. Effective use of sources, for example energy and raw materials

Based on the formulated maintenance objectives the maintenance strategy is established. The maintenance strategy helps to define which maintenance activities need to done, when these maintenance activities need to do and how often these maintenance activities need to done (Muchiri, Martin, Pintelon, & Gelders, 2011). The three most frequently used maintenance strategies are the corrective maintenance strategy, the preventive maintenance strategy and the predictive maintenance strategy. Below these three strategies are explained. In Chapter 4 the maintenance activities related to these strategies are discussed in more detail.

- **The corrective maintenance strategy** focusses on reactive maintenance. It is the simplest maintenance strategy (Horner, Haram, & Munns, 1997). Corrective maintenance is done after equipment failure or after an undesirable situation. The objective of corrective maintenance is to solve the equipment failure or the undesirable situation (DSP & DSC, 2015). Hence, another name for corrective maintenance is failure-based or unplanned maintenance (Horner, Haram, & Munns, 1997). It includes all the activities that are needed to solve the equipment failure or the undesirable situation, these are the activities repair or replacement of equipment.

- **The preventive maintenance strategy** focusses on proactive maintenance and aims to reduce the chance of equipment failure to an acceptable level (DSP & DSC, 2015). It includes all the activities that are needed to reduce the chance of equipment failure, these are the maintenance activities inspection, replacement, calibration, cleaning or lubrication of equipment. Preventive maintenance covers the disadvantages of corrective maintenance, because preventive maintenance is plannable, reduces maintenance costs and reduces downtime (Horner, Haram, & Munns, 1997). Hence, preventive maintenance is also called time-based, planned or cyclic maintenance (Horner, Haram, & Munns, 1997).

- **The predictive maintenance strategy** focusses on assessing the condition of equipment. As a result of the assessment, the best moment to carry out maintenance activities can be determined (DSP & DSC, 2015). The assessment of the equipment condition can be done by a simple visual inspection or by advanced inspection methods and tools (Horner, Haram, & Munns, 1997). Predictive maintenance is also called conditioned-based maintenance.

Next, the corrective, preventive and predictive maintenance activities determined by the maintenance strategies, are carried out by the maintenance process. The maintenance process is a cyclic process consisting of five process steps (Campbell, 1995), mentioned below.

1. **Work identification.** The primary function of work identification is to identify the right maintenance activities for the right time (Weber & Thomas, 2005). This means this process step identifies and controls failure modes that affect the equipment performance (Muchiri, Martin, Pintelon, & Gelders, 2011).

2. **Work planning**. The primary function of work planning is to prepare the work execution of maintenance activities, in order to achieve maximum efficiency during work execution (Weber & Thomas, 2005). This means this process step identifies and prepares the needed resources, safety precautions and instructions that are required for the work execution of the maintenance activities (Weber & Thomas, 2005).

3. **Work scheduling**. The primary function of work scheduling is to coordinate the availability of the needed resources (Weber & Thomas, 2005).

4. **Work execution**. The primary function of work execution is to carry out the maintenance activities (Weber & Thomas, 2005).

5. **Closing the job.** The primary function of closing the job is to document what is done and what is found during work execution (Weber & Thomas, 2005).

The key steps of the maintenance process are the process steps work planning and work scheduling, because these process steps determine what needs to be done and when (Muchiri, Martin, Pintelon, & Gelders, 2011). Besides, work execution is crucial for guaranteeing that the required equipment performance are attained (Muchiri, Martin, Pintelon, & Gelders, 2011). So, work planning, work scheduling and work execution are the most important process steps of the maintenance process.

3.2.2 What needs to be measured of the maintenance process

The conceptual performance measurement framework of Muchiri, Pintelon, Gelders & Martin (2011) identifies characteristics that need to be measured, in order to monitor the condition of a maintenance process. The conceptual performance measurement framework divides the characteristics that need to be measured into two parts. The characteristics related to the first part monitor the maintenance process itself. The characteristics related to the second part monitor the results of the maintenance process. The two parts together provide a complete overview of the condition of a maintenance process. Both parts are discussed below in more detail.

The characteristics related to the first part of the conceptual performance measurement framework monitor the maintenance process itself. In order to monitor the maintenance process well, each process step of the maintenance process that adds value to the results of the maintenance process, needs to be measured. These are the process steps work identification, work planning, work scheduling and work execution (Muchiri, Martin, Pintelon, & Gelders, 2011). By measuring the process step work identification there is monitored how well potential equipment failure is identified and how well is reacted on equipment failure. By measuring the process steps work planning and scheduling there is monitored if maintenance work is not left to chance (Muchiri, Martin, Pintelon, & Gelders, 2011). By measuring the process step work execution there is monitored the effectiveness and efficiency during maintenance execution (Muchiri, Martin, Pintelon, & Gelders, 2011). So, in order to monitor the condition of a maintenance process the process steps work identification, work planning, work scheduling and work execution need to be measured. Shown in Figure 7 on the left side.

The characteristics related to the second part of the conceptual performance measurement framework monitor the results of the maintenance process. The results of the maintenance are directly influenced by the maintenance process and are indirectly influenced by the maintenance objectives and the maintenance strategy. The results of the maintenance process need to be measured by focusing on equipment performance and maintenance costs (Muchiri, Martin, Pintelon, & Gelders, 2011). The equipment performance defines the outcome of the maintenance process and the maintenance costs define the effectiveness and efficiency of the maintenance process (Muchiri, Martin, Pintelon, & Gelders, 2011). So, in order to monitor the condition of a maintenance process equipment performance and maintenance cost need to be measured. Shown in Figure 7 on the right side.

To conclude the conceptual performance measurement framework of Muchiri, Pintelon, Gelders & Martin (2011) shows that both the maintenance process as the results of the maintenance process need to be measured in order to monitor the condition of a maintenance process, see Figure 7. The maintenance process needs to be measured by focusing on the process steps work identification, work planning, work scheduling and work execution. The results of the maintenance process need to be measured by focusing on equipment performance and maintenance costs. So, the condition of a maintenance process can be monitored by measuring six characteristics. However, it is important to consider that this framework is a generic approach to monitor the condition of a maintenance process. Therefore, this conceptual framework provides room for customization. This is mainly the case for the part that monitors the maintenance process itself.

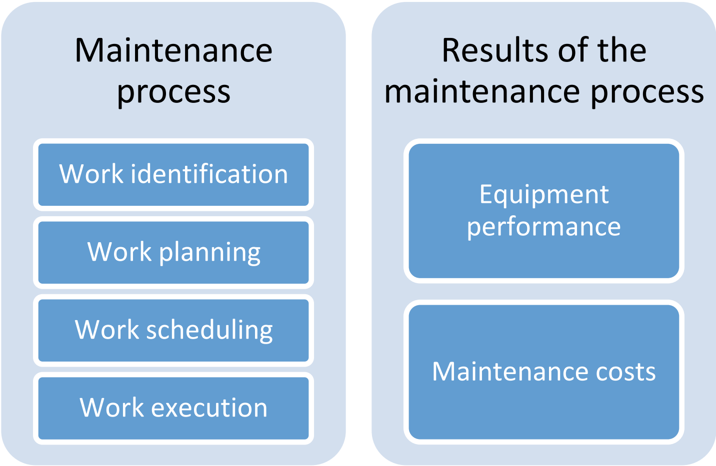

Figure 7; Monitoring the condition of a maintenance process (Muchiri, Martin, Pintelon, & Gelders, 2011)

3.2.3 What needs to be measured of the equipment performance

In the previous sub section is identified that equipment performance needs to be measured in order to monitor the condition of a maintenance process. In this sub section the equipment performance related to the maintenance process are discussed in more detail.

Equipment performance related to the maintenance process can be defined by the production downtime losses (Muchiri, Martin, Pintelon, & Gelders, 2011). The production downtime losses reduce the effectiveness of the equipment (Muchiri & Pintelon, 2008) and therefore do not add value to the manufactured products by the equipment (Dal, Tugwell, & Greatbanks, 2000). The Total Equipment Effectiveness Performance tool divides the production downtime losses into planned downtime losses and unplanned downtime losses (Muchiri & Pintelon, 2008). Shown in Figure 8 on the next page.

The planned downtime losses are a result of preventive maintenance activities and can be defined by the function 'planning rate' (Muchiri, Martin, Pintelon, & Gelders, 2011). This function is dependent on the number of preventive maintenance activities and the time needed for the execution of preventive maintenance activities (Muchiri & Pintelon, 2008). Shown in Figure 8.

The unplanned downtime losses can be defined by the function 'availability rate'. This function is dependent on the reliability of equipment and the time to repair. Shown Figure 8. Since, the primary function of the maintenance process is to reduce or to eliminate equipment failure and consequences of equipment failure, the unplanned downtime represents the results of the maintenance process (Muchiri, Martin, Pintelon, & Gelders, 2011).

To conclude, equipment reliability and time to repair need to be measured in order to monitor the equipment performance as a result of the maintenance process.

3.2.4 Sub conclusion maintenance process

The conceptual framework of Muchiri, Pintelon, Gelders and Martin (2011) shows that both the maintenance process itself as the results of the maintenance process need to be measured in order to monitor the condition of the maintenance process. The maintenance process can be measured by focusing on the process steps work identification, work planning, work scheduling and work execution. The results of the maintenance process can be measured by focusing on the maintenance costs and equipment performance. Next, the equipment performance as a result of the maintenance process can be measured by focusing on the reliability of equipment and the time to repair.

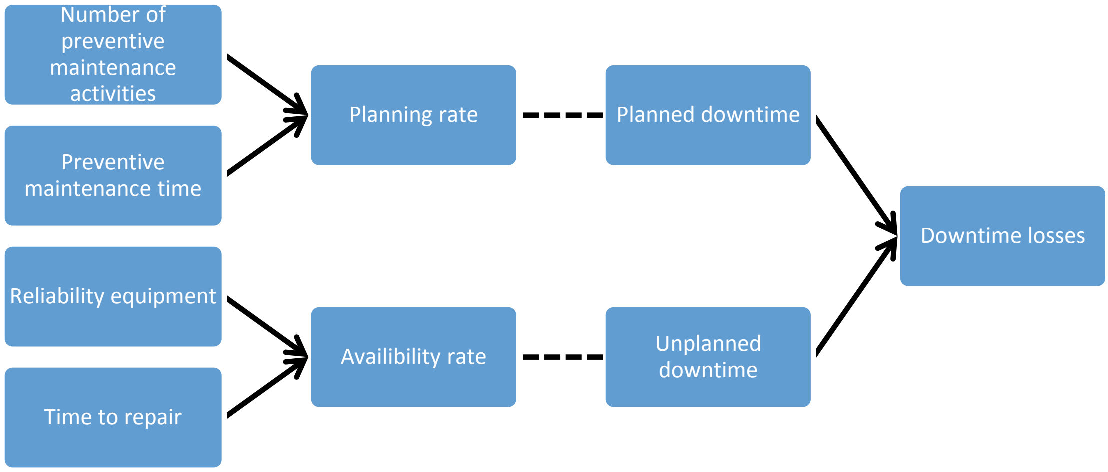

Figure 8; Equipment performance related to a maintenance process (Muchiri, Martin, Pintelon, & Gelders, 2011)

3.3 Literature framework

In the previous sections is identified what defines the incentive of a PBC in the manufacturing industry and is identified what needs to be measured in order monitor the condition of a maintenance process. This section combines the findings from both topics in a literature framework. This literature framework shows what characteristics need to be measured, in order to define the incentive of a PBC and in order to monitor the condition of a maintenance process. In Figure 9 the literature framework is shown. Each cell in the figure represents a characteristic that needs to be measured. The light blue cells in Figure 9 represent the characteristics that need to be measured in order to monitor the condition of a maintenance process. The dark blue cells represent the characteristics that need to be measured in order to define the incentive of a PBC.

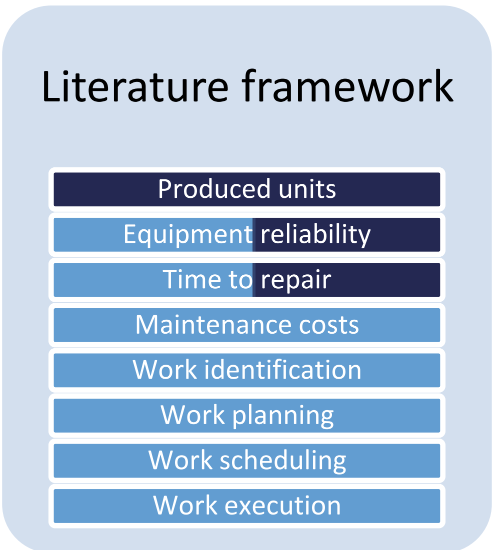

Figure 9; Literature framework for monitoring a maintenance process[1] and defining an incentive of a PBC[2]

[1] Characteristics for monitoring maintenance process represented by light blue cells
[2] Characteristics for defining incentive of a PBC represented by dark blue cells

The characteristics in the literature framework that need to be measured in order to monitor the condition of a maintenance process, arise directly from section 3.2.4. The characteristics in the literature framework that need to be measured in order to define the incentive of a PBC, are a combination of the findings from section 3.1.4 and 3.2.3. In section 3.1.4 is mentioned that the incentive of a PBC in the manufacturing can be defined by the produced units and/or the availability of equipment. In section 3.2.3 is mentioned that equipment availability is determined by equipment reliability and time to repair. If these two statements of both sections are combined, it can be concluded that the incentive of a PBC can be defined by the produced units and/or equipment reliability in combination with time to repair.

3.4 Sub conclusions literature review

Question 1: Which characteristics can define the incentive of a Performance Based Contract in the manufacturing industry according to literature?

The outcome of a delivered service defines the incentive of a Performance Based Contract in general. In the manufacturing industry the outcome of a delivered service is *equipment availability* and/or *produced units by the equipment.* So, the characteristics *equipment availability* and/or *produced units by the equipment* can define the incentive of a Performance Based Contract in the manufacturing industry.

Question 2: Which characteristics need to be measured in order to monitor the condition of a maintenance process, according to literature?

The characteristics *work identification, work planning, work scheduling* and *work execution* need to be measured in order to monitor the maintenance process itself. The characteristics *maintenance cost, equipment reliability* and *time to repair* need to be measured in order to monitor the results of the maintenance process. All these characteristics together need to be measured, in order to monitor the condition of a maintenance process according to literature.

Based on the findings of the case study done in the next chapter and the formulated requirements from Chapter 5, the literature framework developed in this chapter is customized for the Zor-f plant in Chapter 6.

4 Practice: Case-study at the Zor-f plant

This chapter presents the current state of the maintenance process of the Zor-f plant and the current state of the aspects that have influence on the maintenance process of the Zor-f plant. This case study is performed in order to established who and what have influence on the characteristics from literature that need to be measured in order to define the incentive of the Performance Based Contract (PBC), in practice. Besides, this case study is performed in order to established how the characteristics from literature that need to be measured in order to monitor the condition of the maintenance process, behave in practice. Therefore this chapter answers the third and fourth sub research question of this project, "*What and who has influence in practice on the characteristics from literature that can define the incentive of a Performance Based Contract?* and *"How do, the characteristics from literature that need to be measured in order to monitor the condition of a maintenance process, behave in practice?"*

4.1 Tools used for the case study analysis

This section discusses the tools used for the case study analysis at the Zor-f plant. Below, the three used tools are shortly explained.

- **Objective tree**
  In order to identify the maintenance objectives of the Zor-f plant an objective tree is used. An objective tree is a tool that shows the objectives of an actor. This is a conceptual model that describes how the objectives of an actor can be made operational (Bots, 2014). This tool is used, because it shows the objectives in an organized and hierarchical way. Besides, it shows which sub-objectives need to be accomplished, in order to achieve an objective at a high level. An objective can be made more specific by asking the question: *What means this objective*?

- **Swim lane diagram**
  In order to analyze the maintenance process and the related work order flow of the Zor-f plant swim lane diagrams are used. Due to the fact that a work order flow is an information flow and swim lane diagrams visualize information flows, swim lane diagrams are useful to visualize the maintenance process and the related work order flow of the Zor-f plant. Besides, swim lane diagrams visualize clearly the departments, persons or organizations responsible for a specific part of a process (Roser, 2015). Swim lane diagrams visualize different aspects of a process. These different aspects can be represented by the figures shown in Figure 10.

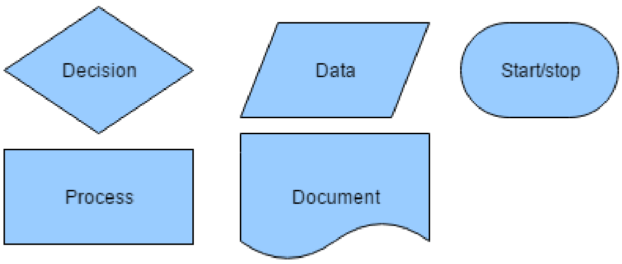

Figure 10; Meaning of figures in swim lane diagrams (Schreuder, n.d.)

- **Pivot table**
  In order to identify the size of the work order flows at the Zor-f plant pivot tables are used. A pivot table is a tool that helps to summarize, order, group and analyze data from spreadsheets (MacDonald, 2004). A pivot table creates a clearly ordered overview of a large amount of data (MacDonald, 2004).

4.2 Organizational structure of the Zor-f plant

In this section is discussed how the maintenance department of the Zor-f plant is related to the rest of the Zor-f plant. Besides, is discussed how the different divisions of the maintenance department are related to each other. Moreover, this section presents who is responsible for what. All of this is discussed by using the organization chart of the Zor-f plant shown in Figure 11 on the next page.

In Figure 11 the organization chart of the Zor-f plant is shown. The light blue cells are represented by employees of DSP and the dark blue cells are represented by employees of DSC. Besides, the cells related to the maintenance department are outlined in red. The figure shows also who is responsible for what. This is presented in the figure by the small cells below each function. For example the figure shows that the plant manager is responsible for the produced product.

The figures shows that on top of the organization of the Zor-f plant the plant manager is located. She/he is responsible for the produced product. The production, maintenance and project departments have together influence on the produced product. The production department is represented by only employees of DSP, the maintenance department is represented by employees of DSC and DSP and the project department is represented by only employees of DSC. This means that both DSC as DSP have influence on the produced product.

The figure shows that on top of the maintenance department the maintenance manager is located. She/he is responsible for all maintenance activities at the Zor-f plant and for achieving the maintenance objectives. The maintenance manager is someone from DSP. The figure shows that below the maintenance manager the maintenance supervisor and maintenance engineers are located. The maintenance supervisor is responsible for the maintenance process and is someone from DSC. The maintenance engineers are responsible for the maintenance strategy and are represented by employees of DSP. This means the maintenance process and the maintenance strategy determine together the performance of the maintenance department. So, DSC and DSP are together responsible for the performance of the maintenance department.

The maintenance strategy and the maintenance process are influenced by the maintenance objectives, because the maintenance objectives determine what is important for the maintenance strategy and the maintenance process. Besides, the maintenance strategy has influence on the maintenance process, because the maintenance strategy determines when and which maintenance activities need to be carried out by the maintenance process.

At last, the figure shows that below the maintenance supervisor the technicians and the planners/schedulers are located. The technicians are responsible for the process step work execution of the maintenance process and the planners/schedulers are responsible for the process steps work planning and scheduling of the maintenance process. Both the technicians as the planners/schedulers are represented by employees of DSC. This means only DSC is responsible for the performance of the maintenance process.

In the next sections the maintenance objectives and the maintenance strategy of the Zor-f plant are discussed in more detail, because they have influence on the maintenance process of the Zor-f plant. Besides, of course the maintenance process itself is discussed in more detail.

[redacted]

Figure 11; Organization chart Zor-f plant

4.3 Maintenance objectives of the Zor-f plant

The maintenance objectives have influence on the maintenance strategy, the maintenance process and the results of maintenance. This is caused by the fact that the maintenance objectives determine what is important for the maintenance strategy, the maintenance process and the results of maintenance. In this section the maintenance objectives of the Zor-f plant are discussed, in order to understand what is important for the maintenance process and the results of the maintenance process at the Zor-f plant.

The maintenance objectives of the Zor-f plant are determined by the produced product by the Zor-f plant, the production process of the Zor-f plant and the equipment of the Zor-f plant. For the maintenance department of the Zor-f plant these things need to be considered as a fact. In order to gain insight into how these things can determine the maintenance objectives, some examples are given below. Below there is mentioned a feature of the produced product, the production process or the equipment of the Zor-f plant. Next, the consequences of this feature are shown.

- **Product:** 7-ADCA is a pharmaceutical product → quality standard for this product are high → products with quality defects are quickly disapproved → consequences of equipment failure are large → minimize equipment failure → reliable equipment is required

- **Production process:** [redacted]

- **Equipment:** [redacted]

If all the features of the produced product, the production process and the equipment of the Zor-f plant are considered, finally five important maintenance objectives for the Zor-f plant can be identified. They are mentioned below, from important to less important. In appendix B the five maintenance objectives are described in more detail by an objective tree.

1. Ensuring plant safety and environment
2. Ensuring effectiveness and efficiency in work planning
3. Ensuring effectiveness and efficiency in work execution
4. Ensuring plant functionality, mainly equipment availability and reliability
5. Ensuring cost effectiveness in maintenance

The five maintenance objectives show that effectiveness and efficiency in work planning and work execution is important for the maintenance process at the Zor-f plant. Moreover, it shows that plant functionality and cost effectiveness in maintenance are important for the results of the maintenance process at the Zor-f plant.

4.4 Maintenance strategy of the Zor-f plant

The maintenance strategy has influence on the maintenance process, because the maintenance strategy determines when and which maintenance activities need to be carried out by the maintenance process. In this section the maintenance strategy of the Zor-f plant is discussed, in order to understand which maintenance activities need to be carried out by the maintenance process of the Zor-f plant.

At the Zor-f plant three maintenance strategies are applied. These are the corrective, preventive and predictive maintenance strategy. In section 3.2 the three maintenance strategies are explained. [redacted]

[redacted]

[redacted]

The maintenance strategy determines which maintenance activities need to be carried out by the maintenance process. There are six maintenance activities that can be carried out by the maintenance process at the Zor-f plant. Below these six maintenance activities are explained.

A corrective maintenance activity:

- **Repair:** Repairing of equipment is recovering equipment that is in an undesired state, in order to obtain equipment that is in a desired state. This can be done for all types of equipment components and can belong to the E&I discipline or the Mechanical Engineering discipline. It depends on the equipment and the needed repair, [redacted].

Both a corrective as a preventive maintenance activity:

- **Replacement:** Replacement of equipment is replacing old equipment for exactly the same new equipment. Replacement is mainly done if the repair costs are too high or if it is not possible to repair the equipment. Replacement can be done for all types of equipment components and can belong to the E&I discipline or to the Mechanical Engineering discipline.

Both a preventive as a predictive maintenance activity:

- **Inspection:** An inspection is done to determine if the equipment performs correctly and if the equipment is in the desired state. An example of an inspection is a wall thickness measurement. An inspection can be done for all types of equipment components and can belong to the E&I discipline or to the Mechanical Engineering discipline. [redacted].

Preventive maintenance activities:

- **Calibration:** Calibration is comparing equipment with a standard. Calibration is done, in order to test if measurement equipment is accurate. Calibrations can be done only for measurement equipment and therefore belong to the E&I discipline. A [redacted].

- **Lubrication:** If equipment contains moving parts lubrication is needed, in order to increase the lifetime of the equipment. For example bearings need to be lubricated. Lubrication belongs to the Mechanical Engineering discipline. [redacted].

- **Cleaning:** If equipment is dirty, cleaning of equipment is needed. Cleaning can be done for all types of equipment components and belongs to the E&I discipline or to the Mechanical Engineering discipline. [redacted]

[redacted]

[redacted]

[redacted]

4.5 Maintenance process of the Zor-f plant

In the previous sections the maintenance objectives and the maintenance strategy of the Zor-f plant, that have influence on the maintenance process, are discussed. In this section the maintenance process itself is discussed.

The maintenance process at the Zor-f plant consists of five process steps. Below the five process steps are shortly explained. In appendix C the process steps are described in more detail by swim lane diagrams.

1. **Gatekeeping**; During this process step is determined if a notification can be forwarded to the process step work planning. A notification is a request document for maintenance help, which includes codes of equipment, a description of the problem and a priority. A notification is forwarded to the process step work planning if the notification contains all the required information and if the notification has a correct prioritization.
2. **Work planning;** During this process step work instructions are created or selected for the execution of a maintenance activity. Besides, the required man-hours, third parties and materials for the execution of a maintenance activity are determined. At last, the budget for a maintenance activity is determined and approved.
3. **Work scheduling;** During this process step is determined if everything what is required for the execution of a maintenance activity is available. If everything is available a maintenance activity is scheduled.
4. **Work execution;** During this process step a maintenance activity is executed. Besides, permits are created, safety measures are taken, safety check are done and material and tool are collected in order to execute the maintenance activity.
5. **Closing the job;** During this process step remarkable findings done during the execution of a maintenance activity are documented and evaluated.

Each process step is dependent on its previous process steps. The highest dependency exists between the process step work execution and its previous process step work planning. These two process steps are more dependent on each other than the other process steps and their previous process steps according [redacted], [redacted] & [redacted] (Appendix A). For example work execution is dependent on work planning, due to the fact that during work planning materials are selected that are used during work execution.

In additional, both process steps have a major influence on the results of the maintenance process, the maintenance costs and the equipment performance (Appendix A, [redacted]). These process steps have a major influence on the maintenance costs, because during these process steps the most costs are made. The process step work planning is responsible for the costs related to materials and related to third parties. These costs are together responsible for [redacted] of the total maintenance cost at the Zor-f plant ([redacted], Appendix A). The process step work execution is responsible for the most costs related to labor. These cost are responsible for [redacted] of the total maintenance costs at the Zor-f plant ([redacted], Appendix A,). So, together the process steps work planning and work execution are responsible for nearly all maintenance costs of the Zor-f plant. Besides, these process steps have a major influence on the equipment performance, because these process steps are directly linked to the equipment of the Zor-f plant. This is caused by the fact that during work planning the materials are selected for the repair of equipment or for the replacement of equipment and this is caused by the fact that during work execution they work on the equipment units.

The corrective maintenance activities discussed in the previous section have one of the five priorities mentioned below.

- **Priority 0;** Maintenance activity has to start directly and finish as soon as possible (call out)
- **Priority 1;** Maintenance activity has to start within 8 hours and finish soon as possible
- **Priority 2;** Maintenance activity has to start within 2 days and finish within 5 days
- **Priority 3;** Maintenance activity has to start within 5 days and finish within 20 days
- **Priority 4;** Maintenance activity has to start within 20 day

The type of maintenance activity, preventive/predictive or corrective, and the priority of a corrective maintenance activity define together which process steps of the maintenance process are carried out. For corrective maintenance activities with priority 2, 3 or 4 all the five process steps are carried out, shown in Figure 14. For preventive/predictive maintenance activities the process steps work scheduling, work execution and closing the job are carried out, shown in Figure 15. The process steps gatekeeping and work planning are skipped for these maintenance activities, due to the fact that these maintenance activities have already passed the gatekeeping and are already planned. This is caused by the fact that preventive/predictive maintenance activities are recurring activities. For corrective maintenance activities with priority 0 or 1 only the process steps work execution and closing the job are carried out, shown in Figure 16. Due to the high priority of these maintenance activities it is not possible to plan and to schedule these maintenance activities. This is caused by the fact that corrective maintenance activities with priority 0 or 1 need to be executed directly. So, there are three different maintenance processes at the Zor-f plant.

Figure 14; Maintenance process Zor-f plant corrective maintenance activities with priority 2, 3 or 4

Figure 15; Maintenance process Zor-f plant preventive/predictive maintenance activities

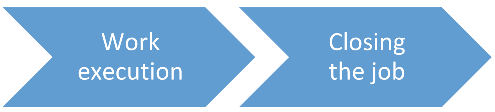

Figure 16; Maintenance process Zor-f plant corrective maintenance activities with priority 0 or 1

Five major problems can be identified in the maintenance process of the Zor-f plant. They are related to the process steps gatekeeping, work planning and work execution. The five problems are mentioned at the next page.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

4.6 Maintenance work order flow of the Zor-f plant

The maintenance process steps discussed in the previous section are connected by an information flow, this information flow is based on work orders and is therefore called a work order flow. This flow helps to track all the maintenance activities at the Zor-f plant (Wireman, 2005). In this section the work order flow of the Zor-f plant is shortly discussed, in order to obtain more information about the process steps of the maintenance process at the Zor-f plant. Such as mentioned in the previous section there are three different maintenance processes at the Zor-f plant. Hence, there are also three different work order flows at the Zor-f plant. In Figure 17 three work order flows are shown. The corrective maintenance activities with priority 2, 3 or 4 follow the work order flow shown in Figure 17 by the red dotted line. The figure shows that the work order flow starts with a notification that is the input for the process step gatekeeping. The output of the process step gatekeeping is a created work order. Next, after each process step the status of the work order is changed, from created to planned, from planned to scheduled, from scheduled to executed and finally from executed to technical complete. Preventive/predictive maintenance activities follow the work order flow shown in Figure 17 by the blue dotted line. The figure shows that the work order flow starts with a preventive/predictive work order that is the input for the process step work scheduling. Next, the status of the work order changes after each process step, in the same way as described for the corrective maintenance activities with priority 2, 3 or 4. Corrective maintenance activities with priority 0 or 1 follow the work order flow shown in Figure 17 by the green dotted line. The figure shows that the work order flow starts with a corrective work order with priority 0 or 1 that is the input for the process step work execution. Next, the status of the work order changes after each process step, in the same way as described for the other two work order flows.

[redacted]

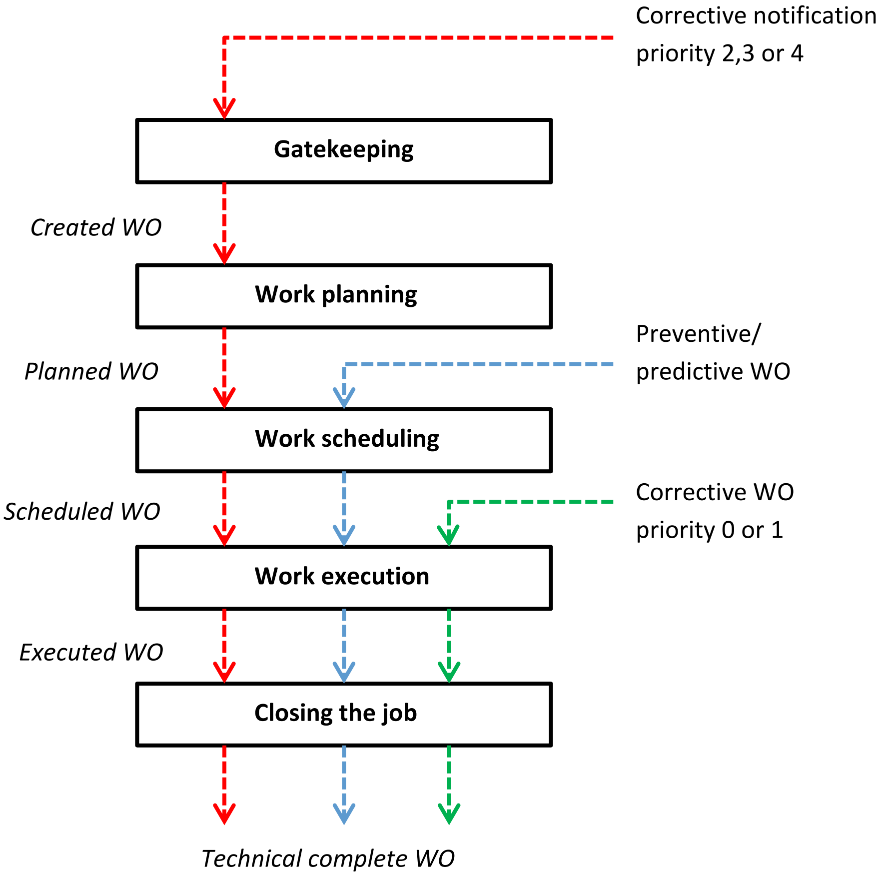

Figure 17; Work order flows Zor-f plant

[redacted]

Figure 18; Distribution work order flows Zor-f plant

4.7 Sub conclusions practice: Case-study at the Zor-f plant

Question 3: What and who has influence in practice on the characteristics from literature that can define the incentive of a Performance Based Contract?

The first characteristic *produced units*, is mainly influence by the production process. Besides, the uptime of equipment has influence on the produced units. The uptime of equipment is determined by the maintenance strategy and the maintenance process. DSP is responsible for the production process and the maintenance strategy. DSC is responsible for the maintenance process. Due to this, mainly DSP has influence on the characteristic *produced units.*

The second characteristic *equipment reliability*, is mainly influence by the maintenance strategy. Besides, the maintenance process has influence on equipment reliability. DSP is responsible for the maintenance strategy and DSC is responsible for the maintenance process. Due to this, both DSP as DSC have influence on the characteristic *equipment reliability*.

The last characteristic *time to repair*, is mainly influence by the maintenance process. DSC is responsible for the maintenance process. Due to this, DSC is the only party that has influence on the characteristic *time to repair*.

Question 4: How do, the characteristics from literature that need to be measured in order to monitor the condition of a maintenance process, behave in practice?

At the Zor-f plant the characteristics *equipment reliability, time to repair, maintenance cost, work planning* and *work execution* are the most important characteristics, since these characteristics are related to the maintenance objectives of the Zor-f plant.

Besides, the characteristics [redacted] have the most problems at the Zor-f plant. [redacted]

At last, the characteristic *work execution* is strongly dependent of the characteristic *work planning* at the Zor-f plant. In addition, both characteristics have a major influence on the characteristics *equipment reliability, time to repair* and *maintenance cost* at the Zor-f plant.

Based on the knowledge obtained in this chapter the literature framework from Chapter 3 is customized for the Zor-f plant in Chapter 6.

5 Design requirements for a Performance Measurement System

This chapter presents the design requirements and constraints for the Performance Measurement System (PMS) designed in the next chapter. In the first section the architecture of the PMS is explained. Next, the design requirements and constraints for the PMS itself are discussed. Afterwards, the design requirements and constraints for the Performance Indicators of the PMS are discussed. In section 2.4 is explained how this is done.

5.1 Architecture of a Performance Measurement System

A PMS can be structured as shown in Figure 19. The figure shows that a PMS consists of two levels. The first level, the PMS itself, defines what needs to be monitored/defined by the PMS. The second level, the Performance Indicators, defines how to measure what needs to be monitored/defined by the PMS. To conclude, a PMS consists of a set of Performance Indicators.

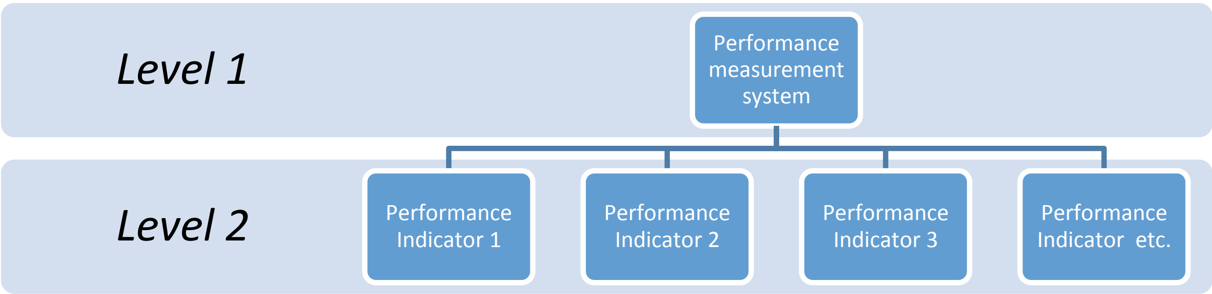

Figure 19; Architecture of a Performance Measurement System

Both for the PMS as for the Performance Indicators design requirements and constraints need to be formulated. The requirements and constraints for the PMS are related to what will and will not be monitored/defined by the PMS. The requirements and constraints for the Performance Indicators are related to how to measure what needs to be monitored/defined by the PMS. In the next sections the design requirements and constraints both for the system as for the Performance Indicators of the system are discussed.

5.2 Requirements and constraints for a Performance Measurement System

This section presents the requirements and constraints for the PMS. A functional requirement is in this section defined as something that needs to be done by the PMS (Defense acquisition university press, 2001). A constraint is defined in this section as a restriction for the set of functional requirements. A constraint limits the range of possible PMSs that can be designed in the next chapter (Requirements and Constraints, 2008).

Functional requirements:

1. The PMS should monitor at least one characteristic on strategical level of the maintenance department (Appendix A, [redacted]).
2. The PMS should monitor at least one characteristic on tactical level of the maintenance department (Appendix A, [redacted]).
3. The PMS should monitor at least one characteristic on operational level of the maintenance department (Appendix A, [redacted]).
4. The PMS should monitor the maintenance process itself by more than half of the characteristics monitored/defined by the PMS (Stork technical services, 2016).

5. The PMS should monitor at least two characteristics of the results of the maintenance process (Stork technical services, 2016).
6. The PMS should monitor more than half of the identified problems in the maintenance process (Appendix A, [redacted]) (Stork technical services, 2016).
7. The PMS should monitor all the process steps of the maintenance process that are highly dependent on each other (Appendix A, [redacted]).
8. The PMS should monitor all important and relevant maintenance objectives (Stork technical services, 2016).
9. The PMS should define the incentive of the PBC at least by one characteristic (Appendix A, [redacted]).

Constraints:

1. The PMS must define the incentive of the PBC by the outcome of the maintenance process (Hypko, Tilebein, & Gleich, 2010a).
2. The PMS must define the incentive of the PBC by only characteristics that can be influenced by the contractor (Stork technical services, 2016).
3. The PMS must monitor/define more characteristics than only the financial characteristics (Stork technical services, 2016).
4. The PMS must monitor more characteristics than only the characteristics that define the incentive of the PBC (Behn & Kant, 1999).
5. The PMS must not monitor/define more than ten characteristics (Stork technical services, 2016) (Appendix A, [redacted]).

If the requirements and constraints mentioned above are met by the PMS designed in the next chapter, a PMS is designed that monitors and defines the right characteristics, in order to monitor the condition of the maintenance process of the Zor-f plant and in order to define the incentive of the PBC between DSC and DSP.

5.3 Requirements and constraints for Performance Indicators

This section presents the requirements and constraints for the Performance Indicators of the PMS. A functional requirement is in this section defined as something that needs to be done by a Performance Indicator of the PMS (Defense acquisition university press, 2001). A constraint is defined in this section as a restriction for the functional requirement. A constraint limits the range of possible Performance Indicators that can be used (Requirements and Constraints, 2008).

Functional requirement:

1. A Performance Indicator should measure a characteristic needs to be monitored/defined by the PMS.

Constraints:

1. A Performance Indicator must be understood without explanation (Parida & Kumar, 2006).
2. A Performance Indicator should measure one characteristic needs to be monitored/defined by the PMS (Parida & Kumar, 2006).
3. A Performance Indicator must be calculated by only quantitative data (Parida & Kumar, 2006).
4. A Performance Indicator should show different values over a long period of time (Stork technical services, 2016).

5. A Performance Indicator should not measure an activity (Appendix A, [redacted]).

If the requirement and constraints mentioned above are met by the Performance Indicators of the PMS designed in the next chapter, a PMS is designed that consists of the right Performance Indicators, in order to measure the characteristics that need to be monitor/defined by the PMS.

6 Design of a Performance Measurement System

This chapter presents the design of the Performance Measurement System (PMS) for the Zor-f plant. Before the PMS can be designed, the characteristics that need to be measured by the PMS, are identified. Next, Performance Indicators are selected for the identified characteristics that need to be measured. After the selection of the Performance Indicators, is defined who needs to managed the selected Performance Indicators. Finally, all the findings from this chapter are combined in a PMS for the Zor-f plant.

Therefore, this chapter will answer the fifth, sixth and seventh sub research question, "*Which characteristics need to be measured in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the Performance Based Contact between DSC and DSP?", "Which Performance Indicators need to be used in order to measure the identified characteristics?"* and "*Who needs to manage the selected Performance Indicators?"*

6.1 Identification of characteristics that need to be measured

This section identifies what needs to be measured by the PMS. First is identified what needs to be measured in order to monitor the condition of the maintenance process of the Zor-f plant. Next, is identified what needs to be measured in order to define the incentive of the Performance Based Contract (PBC) between DSC and DSP. For both topics the characteristics from the literature framework, shown in Figure 9, are used as starting point. Next, based on the findings of the case study, the design requirements and constraints the characteristics from the literature framework are customized for the Zor-f plant. At last, all the identified characteristics are combined in a current state framework. This framework defines which characteristics need to be measured, in order to monitor the condition of the maintenance process of the Zor-f plant and to define incentive of the PBC between DSC and DSP.

6.1.1 Monitoring the maintenance process of the Zor-f plant

This sub section identifies what needs to be measured, in order to monitor the condition of the maintenance process of the Zor-f plant. The literature framework in Figure 9 shows that *equipment reliability*, *time to repair* and *maintenance cost* need to be measured in order to monitor the condition of a maintenance process. In section 4.7 of the case study is shown that these characteristics are related to the maintenance objectives of the Zor-f plant. One of the design requirements from Chapter 5 shows that all the important and relevant maintenance objectives need to be monitored by a PMS. Based on the findings of the case study and the design requirements can be concluded that the characteristics *equipment reliability, time to repair* and *maintenance cost* need to be measured by the PMS, in order to monitor the condition of the maintenance process of the Zor-f plant.

The literature framework in Figure 9 shows that *work identification* and *work scheduling* need to be measured, in order to monitor the condition of a maintenance process. Section 4.7 of the case study shows that both characteristics are not related to the maintenance objectives of the Zor-f plant, have hardly any problems and have hardly influence on other characteristics. The design requirements formulated in Chapter 5 show that more than half of the identified problems in the maintenance process, all the process steps of the maintenance process that are highly dependent on each other and all the important and relevant maintenance objectives, need to be monitored by the PMS. Based on the findings of the case study and the design requirements can be concluded that the characteristics *work identification* and *work scheduling* do not need to be measured by the PMS in order to monitor the condition of the maintenance process of the Zor-f plant.

The literature framework in Figure 9 shows that *work planning* and *work execution* need to be measured in order to monitor the condition of a maintenance process. [redacted]

[redacted] Based on the findings of the case study and the design requirements can be concluded that the characteristics *work planning* and *work execution* need to be measured by the PMS in order to monitor the condition of the maintenance process of the Zor-f plant.

[redacted].
Therefore, labor estimation, work efficiency, first-time right work and schedule compliance need to be measured by the PMS in order to monitor the condition of the maintenance process of the Zor-f plant.

To conclude the seven characteristics *equipment reliability, time to repair*, *maintenance cost*, *labor estimation*, *work efficiency, first-time right work* and *schedule compliance* need to be measured by the PMS in order to monitor the condition of the maintenance process of the Zor-f plant.

6.1.2 Defining the incentive of the PBC between DSC and DSP

This sub section identifies what needs to be measured, in order to define the incentive of the PBC between DSC and DSP. The literature framework from Figure 9, shows that the characteristics *produced units* and/or *equipment reliability* in combination with *time to repair* need to be measured, in order to define the incentive of a PBC. Section 4.7 of the case study shows that mainly DSP has influence on the characteristic *produced units,* that both DSC as DSP have influence on the characteristic *equipment reliability* and that DSC is the only party that has influence on the characteristic *time to repair*. One of the constraints from Chapter 5 shows that the contractor should be the only party which has influence on the outcome of the maintenance process. This is only the case for the characteristic *time to repair* at the Zor-f plant. As a result only the characteristic *time to repair* can be used, in order to define the incentive of the PBC between DSC and DSP.

6.1.3 Sub conclusions identification of characteristics that need to be measured

Based on the findings of the previous two sub sections the literature framework from section 3.3 is customized for the Zor-f plant. This way a current state framework is obtained, that defines which characteristics need to be measured in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the PBC between DSC and DSP. The current state framework is shown in Figure 20. Each cell in the figure represents a characteristic that needs to be measured. The light blue cells represent the characteristics that need to be measured in order to monitor the condition of the maintenance process of the Zor-f plant. The dark blue cells represent the characteristics that need to be measured in order to define the incentive of the PBC between DSC and DSP. The figure shows that seven characteristics need to be measured in order to monitor the condition of the maintenance process of the Zor-f plant and that one characteristic needs to be measured in order to define the incentive of the PBC between DSC and DSP.

Question 5: Which characteristics need to be measured in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the Performance Based Contact between DSC and DSP?

The characteristics *equipment reliability, time to repair*, *maintenance cost*, *labor estimation*, *work efficiency, first-time right work* and *schedule compliance* need to be measured in order to monitor the condition of the maintenance process of the Zor-f plant. The characteristic *time to repair* needs to be measured in order to define the incentive of the Performance Based Contract between DSC and DSP.

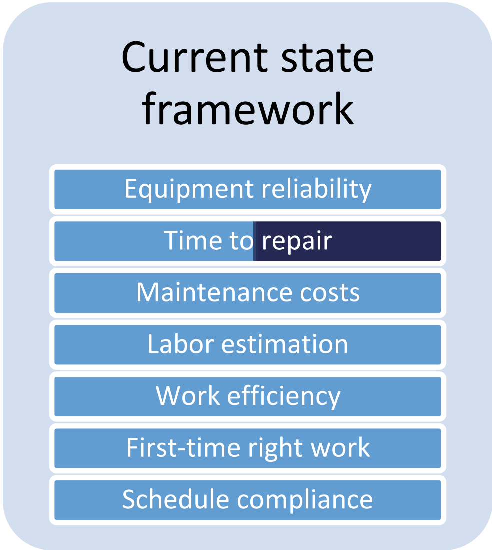

Figure 20; Current state framework for monitoring the maintenance process of the Zor-f plant[3] and defining the incentive of the PBC between DSC and DSP[4]

6.2 Selection of Performance Indicators

In the previous section, the characteristics need to be measured in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the PBC between DSC and DSP, are identified. In this section Performance Indicators are selected. These Performance Indicators measure the identified characteristics of the previous section. The Performance Indicators are selected based on the design requirements and constraints from Chapter 5. Per Performance Indicator the formulas that calculate the Performance Indicator are given. These formulas are based on the formulas mentioned in the papers of Weber & Thomas (2005) and Muchiri P., Pintelon, Gelders, & Martin (2011), but are customized for the Zor-f plant by the researcher of this project. Besides, the goals for the Performance Indicators are defined based on literature. At last, the target of each Performance Indicator is determined also based on literature. The targets given in this report are the targets need to be used by the implementation of the Performance Indicators. After the implementation, the targets need to be reviewed and if required the targets need to be adjusted. See also Chapter 8.

6.2.1 Performance Indicator Mean Time Between Failure (MTBF)

In order to measure the equipment reliability of the Zor-f plant at equipment unit level, the Performance Indicator *Mean Time Between Failure* is used (Torell & Avelar, 2004). It shows the average time between the failure of all equipment units at the Zor-f plant. This Performance Indicator is calculated by the formulas mentioned on the next page. Where loading time of an equipment unit is defined as the scheduled operation time of an equipment unit. The goal for this Performance Indicator is to maximize the Mean Time Between Failure of all equipment units at the Zor-f plant against acceptable costs. This Performance Indicator has a context specific target and is never measured before at the Zor-f plant. Therefore, it not possible to define a target for this Performance Indicator at this moment. The target needs to be defined after the implementation of the Performance Indicator.

$$c(a,b) = \begin{cases} a\text{, if } b = 0 \\ \frac{a}{b}\text{, otherwise} \end{cases} \tag{6.1}$$

$$d(c,n) = \frac{\sum_{i \in I} c}{n} \tag{6.2}$$

[3] Characteristics for monitoring maintenance process of the Zor-f plant represented by light blue cells

[4] Characteristics for defining incentive of the PBC between DSC and DSP represented by dark blue cells

With:

$\boldsymbol{a}$ = Loading time of equipment unit $\boldsymbol{i}$ [days]
$\boldsymbol{b}$ = Number of failure moments of equipment unit $\boldsymbol{i}$ [#]
$\boldsymbol{c}$ = Mean time between failure of equipment unit $\boldsymbol{i}$ [days]
$\boldsymbol{d}$ = Average of the mean time between failure of the set of equipment units [days]
$\boldsymbol{n}$ = Total number of equipment units [#]
$\boldsymbol{i}$ = Equipment unit
$\boldsymbol{I}$ = Set of equipment units

6.2.2 Performance Indicator Mean Time To Repair (MTTR)

In order to measure the time to repair for corrective maintenance activities at the Zor-f plant at equipment unit level, the Performance Indicator *Mean Time To Repair* is used. It shows the average time needed to solve equipment failure of all equipment units at the Zor-f plant. This is also called the average corrective maintenance time. In this project the administrative and logistics delay time are ignored (Stapelberg, 2009). The administrative delay time is ignored, because DSP has influence on this. For example by checking and assigning permits, creating failure forms, creating notifications, etc. See also Appendix C. As mentioned in section 5.2 only the contractor should have influence on the characteristics that define the incentive of a PBC, so in this case on the Performance Indicator *Mean Time To Repair*. By ignoring the administrative delay time this is the case. The logistics delay time is also ignored, because DSP has also influence on this. This is caused by the fact that they determine the spare parts of the equipment of the Zor-f plant. In this way DSP determines which corrective maintenance activities have logistic delay time and which corrective maintenance activities have not logistic delay time. As mentioned above only the contractor should have influence on the characteristics that define the incentive of a PBC, so in this case on the Performance Indicator *Mean Time To Repair*. By ignoring the logics delay time, this is the case. This Performance Indicator is calculated by the formulas mentioned below. The goal for this Performance Indicator is to minimize the mean time to repair of all equipment units at the Zor-f plant. This Performance Indicator has a context specific target and is never measured before at the Zor-f plant. Therefore, it is not possible to define a target for this Performance Indicator at this moment. The target needs to be defined after the implementation of the Performance Indicator.

$$f(e,m) = \begin{cases} 0\text{, if } m = 0 \\ \frac{\sum_{j \in J} e}{m}\text{, otherwise} \end{cases} \qquad (6.3)$$

$$g(f,n) = \frac{\sum_{i \in I} f}{n} \qquad (6.4)$$

With:

$\boldsymbol{e}$ = Repair time of failure moment $\boldsymbol{j}$ of equipment unit $\boldsymbol{i}$ [hours]
$\boldsymbol{f}$ = Mean time to repair equipment unit $\boldsymbol{i}$ [hours]
$\boldsymbol{g}$ = Average of the mean time to repair of the set of equipment units [hours]
$\boldsymbol{n}$ = Total number of equipment units [#]
$\boldsymbol{i}$ = Equipment unit
$\boldsymbol{I}$ = Set of equipment units
$\boldsymbol{m}$ = Number of failure moments of equipment unit $\boldsymbol{i}$ [#]
$\boldsymbol{j}$ = Equipment failure moment of equipment unit $\boldsymbol{i}$
$\boldsymbol{J}$ = Set of failure moments of equipment unit $\boldsymbol{i}$

6.2.3 Performance Indicator Direct maintenance costs

In order to measure the maintenance cost of preventive/predictive and corrective maintenance activities the Performance Indicator *Direct maintenance cost* is used. It shows the total actual costs regarding to labor and material for all maintenance activities at the Zor-f plant. The direct maintenance cost Performance Indicator is calculated by the formula mentioned below. The goal for this Performance Indicator is to minimize the maintenance cost, while preserving good equipment performance. This Performance Indicator has a context specific target. According to [redacted] (Appendix A) direct maintenance cost lower than [redacted] per month can be considered as a good performance.

$$l\,(h,k) = h + k \qquad (6.5)$$

$\boldsymbol{l}$ = Total direct maintenance cost [euros]
$\boldsymbol{h}$ = Total cost of corrective maintenance activities [euros]
$\boldsymbol{k}$ = Total cost of preventive and predictive maintenance activities [euros]

6.2.4 Performance Indicator Labor estimation

In order to measure the accuracy of the labor estimation for the execution of preventive/predictive and corrective maintenance activities, the Performance Indicator *Labor estimation* is used (Weber & Thomas, 2005). The labor estimation is calculated by the formulas mentioned below. The goal for this Performance Indicator is to maximize the amount of work orders with an accurate labor estimation. If more than 90% of the work orders have an accurate labor estimation, the performance of the indicator are good (Weber & Thomas, 2005).

$$r(p,q) = \begin{cases} 1, \text{ if } p - 10\% < q < p + 10\% \\ 0, \text{otherwise} \end{cases} \qquad (6.6)$$

$$s(r,n) = \frac{\sum_{i \in I} r}{n} * 100\% \qquad (6.7)$$

With:

$\boldsymbol{p}$ = Estimated labor hours of work order $\boldsymbol{i}$ [hours]
$\boldsymbol{q}$ = Actual labor hours of work order $\boldsymbol{i}$ [hours]
$\boldsymbol{s}$= % work orders with an accurate labor estimation [%]
$\boldsymbol{r}$= The number of work orders with an accurate labor estimation [#]
$\boldsymbol{n}$ = Total number of executed work orders [#]
$\boldsymbol{i}$= Executed work order
$\boldsymbol{I}$= Set of executed work orders

6.2.5 Performance Indicator Man-power efficiency

In order to measure the work efficiency during the execution of preventive/predictive and corrective maintenance activities, the Performance Indicator *Man-power efficiency* is used. The man-power efficiency is calculated by the formulas mentioned below. The goal of this Performance Indicator is to minimize the time of indirect and unproductive activities. The target of this Performance Indicator is based on a bench market. For the Zor-f plant different bench markets can be used. The bench market of maintenance on site defines a target of 48 % man-power efficiency (Binnert, n.d.). The bench market based on type of work, so the combination of mechanical engineering and E&I work, defines a target of 44% man-power efficiency (Walravens, 2011).

$$w(t,u,v) = \frac{\sum t}{(\sum t + \sum u + \sum v)} * 100\% \qquad (6.8)$$

$$x(w,n) = \frac{\sum_{i \in I} w}{n} \qquad (6.9)$$

With:

$\boldsymbol{t}$ = Time direct productive activities of work order $\boldsymbol{i}$ [minutes]
$\boldsymbol{u}$ = Time indirect productive activities of work order $\boldsymbol{i}$ [minutes]
$\boldsymbol{v}$ = Time unproductive activities of work order $\boldsymbol{i}$ [minutes]
$\boldsymbol{w}$ = Man-power efficiency work order $\boldsymbol{i}$ [%]
$\boldsymbol{x}$ = Average man-power efficiency of the set of executed work orders [%]
$\boldsymbol{n}$ = Total number of executed work orders [#]
$\boldsymbol{i}$= Executed work order
$\boldsymbol{I}$= Set of executed work orders

6.2.6 Performance Indicator Rework

In order to measure the first-time right work of preventive/predictive and corrective maintenance activities, the Performance Indicator *Rework* is used. The Performance Indicators shows the amount of work that is not executed the first time right. The Performance Indicator is calculated by the formulas mentioned below. The goal of this Performance Indicator is to minimize the amount of work orders that needs rework. If less than 3 % of the work orders is rework, the performance of the indicator are good (Weber & Thomas, 2005).

$$z(y) = \begin{cases} 1, \text{if } y = \text{rework} \\ 0, \text{otherwise} \end{cases} \tag{6.10}$$

$$\alpha(z,n) = \frac{\sum_{i \in I} z}{n} * 100\% \tag{6.11}$$

With:

$\boldsymbol{y}$ = Work order $\boldsymbol{i}$
$\boldsymbol{z}$ = The number of work orders that is rework [#]
$\boldsymbol{\alpha}$ = % executed rework orders of the set of executed work orders [%]
$\boldsymbol{n}$ = Total number of executed work orders [#]
$\boldsymbol{i}$= Executed work order
$\boldsymbol{I}$= Set of executed work orders

6.2.7 Performance Indicator Schedule compliance

In order to measure the amount of preventive/predictive and corrective maintenance activities that are executed in their scheduled period, the Performance Indicator *Schedule compliance* is used. For preventive/predictive maintenance activities the scheduled period is the time window that is defined by SAP. For corrective maintenance activities the priority of the notification defines the scheduled period, for example a corrective maintenance activity with priority 2 needs to be executed within 5 days. The Performance Indicator is calculated by the formulas mentioned below. The goal for this Performance Indicator is to maximize the amount of work orders that is executed in its scheduled period. If more than 90% of the work orders are executed in their scheduled period, the performance of the indicator are good (Weber & Thomas, 2005).

$$\delta(\beta,\gamma) = \begin{cases} 1, \text{if } \beta = \gamma \\ 0, \text{otherwise} \end{cases} \tag{6.12}$$

$$\varepsilon(\delta,n) = \frac{\sum_{i \in I} \delta}{n} * 100\% \tag{6.13}$$

With:

$\boldsymbol{\beta}$ = Scheduled period of work order execution of work order $\boldsymbol{i}$ [date]
$\boldsymbol{\gamma}$ = Actual executed period of work execution of work order $\boldsymbol{i}$ [date]
$\boldsymbol{\delta}$ = The number of work orders executed in their scheduled period [#]
$\boldsymbol{\varepsilon}$ = % work orders executed in their scheduled period of the set of executed work order [%]
$\boldsymbol{n}$ = Total number of executed work orders [#]
$\boldsymbol{i}$= Executed work order
$\boldsymbol{I}$= Set of executed work orders

6.2.8 Sub conclusion selection Performance Indicators

Question 6: Which Performance Indicators need to be used in order to measure the identified characteristics?

The Performance Indicators *Mean Time Between Failure (MTBF)*, *Mean Time To Repair (MTTR), direct maintenance cost*, *labor estimation, man-power efficiency*, *rework* and *schedule compliance* need to be used in order to measure the identified characteristics.

6.3 Management of Performance Indicators

This sub section defines who needs to manage the Performance Indicators selected in the previous section. How this is done is explained in section 2.5.

Each organization can be divided into three levels, a strategical level, a tactical level and an operational level. All these levels need to be managed (Arts, Knapp, & Mann, 1998). The highest level, the strategical level, is related to the long term objectives. For the maintenance department of the Zor-f plant the maintenance strategy and the results of maintenance are related to this level (DSP & DSC, 2015). The middle level, the tactical level, is related to the semi-long term objectives. For the maintenance department of the Zor-f plant the planning and scheduling of maintenance activities is related to this level (DSP & DSC, 2015). The lowest level, the operational level, is related to short term objectives. For maintenance department of the Zor-f plant the execution of maintenance activities is related to this level (DSP & DSC, 2015).

The selected Performance Indicators *Mean Time Between Failure, Mean Time To Repair* and *direct maintenance cost* are related to the strategical level, because they are related the results of maintenance. The Performance Indicator *labor estimation* is related to the tactical level, because the Performance Indicator is related to the planning of maintenance activities. The Performance Indicators *man-power efficiency, rework* and *schedule compliance* are related to the operational level, because they are related to the execution of maintenance activities. So, Performance Indicators are related to all the three levels.

DSP is responsible for the strategical level of the maintenance department of the Zor-f plant. DSC is responsible for the tactical and operational level of the maintenance department of the Zor-f plant (DSP & DSC, 2015). Therefore, DSP has to manage the Performance Indictors *Mean Time Between Failure, Mean Time To Repair* and *direct maintenance cost*. DSC has to manage the Performance Indicators *labor estimation, man-power efficiency, rework* and *schedule compliance*. Shown in Figure 21 on the next page.

Question 7: Who needs to manage the selected Performance Indicators?

DSP needs to manage the Performance Indicators *Mean Time Between Failure (MTBF)*, *Mean Time To Repair (MTTR)* and *direct maintenance cost*. DSC needs to manage the Performance Indicators *labor estimation, man-power efficiency*, *rework* and *schedule compliance*.

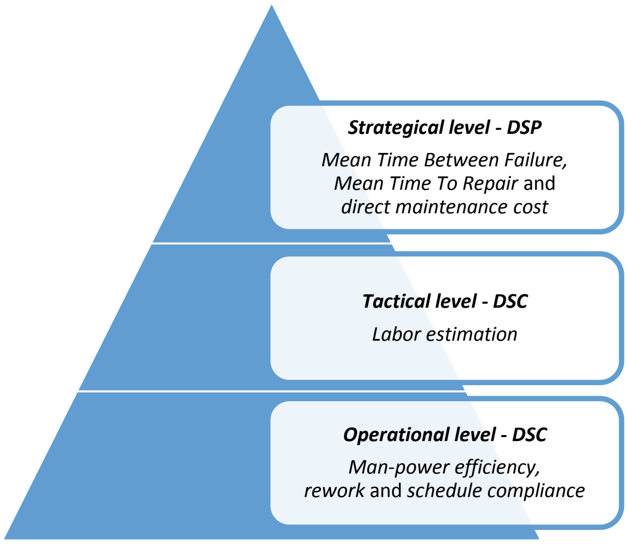

Figure 21; Management of selected Performance Indicators

6.4 Sub conclusions design of a Performance Measurement System

In this section the PMS for the Zor-f plant is designed, by combining all the findings of the previous sections. This results is a PMS for the Zor-f plant as shown in Figure 22. The figure shows that seven Performance Indicators of the PMS monitor the condition of the maintenance process of the Zor-f plant. From the seven Performance Indicators three Performance Indicators need to be managed by DSP, these are the Performance Indicators *Mean Time Between Failure (MTBF)*, *Mean Time To Repair (MTTR)* and *direct maintenance cost* related to the result of the maintenance process. Besides, four Performance Indicators need to be managed by DSC, this is the Performance Indicator *labor estimation* related to work planning and the Performance Indicators *man-power efficiency*, *rework* and *schedule compliance* related to work execution. The figure shows also that one Performance Indicator of the PMS defines the incentive of the PBC between DSC and DSP. This is the Performance Indicator *Mean Time To Repair (MTTR),* which needs to be managed by DSP and is related to the result of the maintenance process. So, the PMS from Figure 22 monitors the condition of the maintenance process of the Zor-f plant and defines the incentive of the PBC between DSC and DSP.

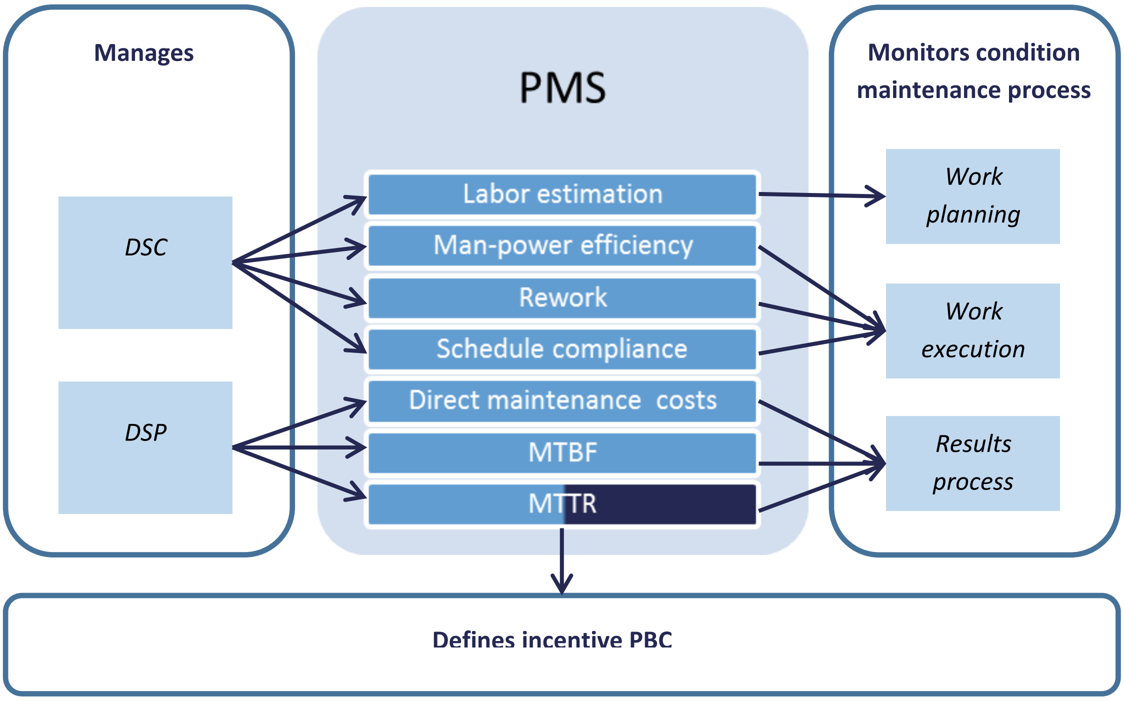

Figure 22; Performance Measurement System for the Zor-f plant

7 Evaluation of the Performance Measurement System

This chapter evaluates the Performance Measurement system (PMS) designed in the previous chapter. First, is evaluated if the PMS is correctly designed in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the Performance Based Contract (PBC) between DSC and DSP. Next, is evaluated if the use of the PMS results in the intended behavior. This is done by evaluating if using the PMS for managing the maintenance process, has the potential to improve the maintenance process and the equipment performances of the Zor-f plant. Besides, this is done by evaluating if using the PMS for managing the PBC, has the potential to stimulate DSC to carry out an effective and efficient maintenance process. In addition, is evaluated if using the PMS for managing the PBC, aligns the objectives of DSC and DSP.

Therefore, this chapter will answer the eighth, ninth and tenth sub research question, *"Has, using the performance measurement system for managing the maintenance process of the Zor-f plant, the potential to improve the maintenance process and equipment performance of the Zor-f plant?"*, "*Has, using the performance measurement system for managing the Performance Based Contract between DSC and DSP, the potential to stimulate DSC to carry out an effective and efficient maintenance process?"* and "*If the performance measurement system is used to manage the Performance Based Contract between DSC and DSP, are the objectives of DSC and DSP aligned?"*.

7.1 Evaluation of the Performance Measurement System based on requirements

This section evaluates if the performance measurement designed in the previous chapter is correctly designed, so if the PMS meets the design requirements and constraints from Chapter 5. First, the PMS is evaluated on the design requirements and constraints related to the PMS from section 5.2. Next, the PMS is evaluated on the design requirements and constraints related to the Performance Indicators from section 5.3. At the same time the current PMS is also evaluated on the design requirements and constraints of this project, in order to approve the new PMS designed in this project is better designed than the current PMS.

7.1.1 Evaluation based on PMS requirements

In this sub section, the current PMS and the PMS designed in the previous chapter, are evaluated on the design requirements and constraints related to the PMS from section 5.2. If a PMS meets all the design requirements and constraints, the PMS monitors and defines the right characteristics, in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the PBC between DSC and DSP.

The researcher of this project has established, based on the information from section 4.3, section 4.7, section 6.1, Figure 21 and Figure 22, if the current PMS meets the design requirements and constraints and if the new PMS meets the design requirements and constraints. For example it is established that the first functional requirement, 'the PMS should monitor at least one characteristic on strategical level of the maintenance department', is met by the new PMS, because Figure 21 shows that three Performance Indicators of the new PMS, *Mean Time Between Failure, Mean Time To Repair* and *direct maintenance cost,* are related to the strategical level of the maintenance department of the Zor-f plant. Or for example it is established that the fourth constraint, 'the PMS must monitor more characteristics than only the characteristics that define the incentive of the PBC', is met by the new PMS, because Figure 22 shows that one Performance Indicator is related to the incentive of the PBC and shows that the other Performance Indicators of the system are not related to the incentive of the PBC. In Appendix D is explained for the current and for the new PMS per design requirement/constraint why the design requirement/constraint is met or is not met. Next, the decisions made by the researcher of this project are reviewed by the plant manager ([redacted]) and by maintenance supervisor ([redacted]) of the Zor-f plant. This review was done separately with the plant manager and separately with the maintenance supervisor. Both reviews consisted of three parts. The first part of the review was an explanation of the new PMS. The second part of the review was the providing of a list with the final decisions of the researcher. This list shows per requirement/constraint if the requirement/constraint is met by the current PMS and by the new PMS, according to the researcher of this project. Finally, based on the provided information, the plant manager and the maintenance supervisor approved the decisions of the researcher. The results of the process described above are presented in Table 1. The tables gives an overview of the requirements and constraints meet and do not meet by the current and by the new PMS.

Table 1 shows that four requirements and two constraints are met by the current PMS. In addition, the table shows that all the requirements and constraints are met by the new PMS. This means the current PMS does not monitor and does not define the right characteristics, in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the PBC between DSC and DSP. In addition, the new PMS monitors and defines the right characteristics, in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the PBC between DSC and DSP.

Table 1; Evaluation current and new PMS based on PMS requirements and constraints

	Functional requirements:	**Current PMS**	**New PMS**
1	The PMS should monitor at least one characteristic on strategical level of the maintenance department (Appendix A, [redacted]).	✓	✓
2	The PMS should monitor at least one characteristic on tactical level of the maintenance department (Appendix A, [redacted]).		✓
3	The PMS should monitor at least one characteristic on operational level of the maintenance department (Appendix A, [redacted]).	✓	✓
4	The PMS should monitor the maintenance process itself by more than half of the characteristics monitored/defined by the PMS (Stork technical services, 2016).		✓
5	The PMS should monitor at least two characteristics of the results of the maintenance process (Stork technical services, 2016).	✓	✓
6	The PMS should monitor more than half of the identified problems in the maintenance process (Appendix A, [redacted]) (Stork technical services, 2016).		✓
7	The PMS should monitor all the process steps of the maintenance process that are highly dependent on each other (Appendix A, [redacted]).		✓
8	The PMS should monitor all important and relevant maintenance objectives (Stork technical services, 2016).		✓
9	The PMS should define the incentive of the PBC at least by one characteristic (Appendix A, [redacted]).	✓	✓
	Constraints:		
1	The PMS must define the incentive of the PBC by the outcome of the maintenance process (Hypko, Tilebein, & Gleich, 2010a).		✓
2	The PMS must define the incentive of the PBC by only characteristics that can be influenced by the contractor (Stork technical services, 2016).		✓
3	The PMS must monitor/define more characteristics than only the financial characteristics (Stork technical services, 2016).	✓	✓
4	The PMS must monitor more characteristics than only the characteristics that define the incentive of the PBC (Behn & Kant, 1999).		✓
5	The PMS must not monitor/define more than ten characteristics (Stork technical services, 2016) (Appendix A, [redacted]).	✓	✓

7.1.2 Evaluation based on Performance Indicator requirements

In this sub section, the PMS designed in the previous chapter and the current PMS, are evaluated on the design requirements and constraints related to the Performance Indicators from section 5.3. If the design requirement and constraints are met by all the Performance Indicators of a PMS, the PMS consists of the right Performance Indicators, in order to measure all the characteristics need to be monitored/defined by the PMS.

If the design requirement and constraints are met by the Performance Indicators of the current and new PMS, is established in the same way and during the same review moments as described in the previous sub section. In Appendix D is shown per Performance Indicator of the current PMS and per Performance Indicator of the new PMS if the Performance Indicator meets or does not meet the requirement and constraints. The results of this are presented in Table 2. The table shows the percentage of Performance Indicators of a PMS meets a design requirement or a constraint.

Table 2; Evaluation current and new PMS based on Performance Indicator requirement and constraints

	Functional requirement:	% PI of current PMS meets requirement or constraint	% PI of new PMS meets requirement or constraint
1	A Performance Indicator should measure a characteristic needs to be monitored/defined by the PMS.	100	100
	Constraints:		
1	A Performance Indicator must be understood without explanation (Parida & Kumar, 2006).	75	100
2	A Performance Indicator should measure one characteristic needs to be monitored/defined by the PMS (Parida & Kumar, 2006).	100	100
3	A Performance Indicator must be calculated by only quantitative data (Parida & Kumar, 2006).	63	100
4	A Performance Indicator should show different values over a long period of time (Stork technical services, 2016).	50	-
5	A Performance Indicator should not measure an activity (Appendix A, [redacted]).	50	100

Table 2 shows that one design requirement and one constraint are met by all the Performance Indicators of the current PMS. Next, one constraint is met by 75% of the Performance Indicators of the current PMS, one constraint is met by 63% of the Performance Indicators of the current PMS and two constraints are met by 50% of the Performance Indicators of the current PMS. The table shows also that all the Performance Indicators of the new PMS meet the design requirement and all the constraints. Except the fourth constraint. This constraint has not a value for the new PMS, because currently it is not possible to define if the Performance Indicators of the new PMS meet this constraint. This can be only determined after the implementation of the PMS. To conclude, the current PMS does not consist of the right Performance Indicators, in order to measure the characteristics need to be monitored/defined by the PMS. The new PMS consists of the right Performance Indicators, in order to measure the characteristics need to be monitored/defined by the PMS.

7.1.3 Sub conclusions evaluation PMS based on requirements

To conclude the new PMS monitor and defines the right characteristics and consists of the right Performance Indicators, in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the PBC between DSC and DSP. This means the new PMS is correctly designed, in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the PBC between DSC and DSP.

Besides, the evaluation of the current PMS shows that the current PMS does not monitor and define the right characteristics and does not consist of the right Performance Indicators, in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the PBC between DSC and DSP. This means the current PMS is not correctly designed, in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the PBC between DSC and DSP.

7.2 Evaluation managing the maintenance process of the Zor-f plant

The previous section shows that the new PMS is correctly designed in order to monitor the condition of the maintenance process of the Zor-f plant and to define the incentive of the PBC between DSC and DSP. In this section is evaluated if using the new PMS for managing the maintenance process, has the potential to improve the maintenance process and the equipment performance of the Zor-f plant.

This is done by using the DMAIC (Define-Improve-Analyze-Improve-Control) method. This is an often used quantitative method for problem solving and process improvement (UNC Plus Delta, 2017). For this reason the method can be used to evaluate the potential improvement of the maintenance process and equipment performance of the Zor-f plant. In literature the functions of each stages of the DMAIC method are defined in different ways (Mast & Lokkerbol, 2012). In this evaluation the functions of the define, measure, improve and control stage are defined as:

- **Define:** to identify scenarios
- **Measure:** to quantify the current state of the maintenance process and equipment performance.
- **Improve:** to quantify the expected future state of the maintenance process and equipment performance
- **Check:** to define the potential improvement of the maintenance process and the equipment performance

As shown above the analyze stage is skipped in this evaluation. Due to analyzing of the current state of the maintenance process and equipment performance is not needed in order to improve the maintenance process. Since, there is already defined a way to improve the maintenance process, namely by using the PMS designed in the previous chapter.

7.2.1 Define: Scenarios

Due to the limited time for this project, it is not feasible to quantify the potential improvement of the maintenance process for each work order and to quantify the potential improvement of the equipment performance for each equipment unit. Therefore, the evaluation is done for a limited number of scenarios. There is chosen to use eight scenarios, because it is timewise feasible to evaluate eight scenarios and it provides enough information in order to generalize the conclusions of the eight scenarios. For the scenarios a distinction is made between preventive maintenance and corrective maintenance, since the differences between the maintenance process of preventive and corrective maintenance are large. As shown in Chapter 4. Besides, the scenarios are related to equipment units. The equipment units with the most work orders in total in 2016 at the Zor-f plant are selected for the scenarios. This way the values of the Performance Indicators are calculated/estimated over more work orders than if equipment units with few work orders in 2016 are used. As a result more reliable values of Performance Indicators are obtained. For example if the Performance Indicator *schedule compliance* is calculated over 50 work orders, the value of the Performance Indicator is more reliable than if the Performance Indicator *schedule compliance* is calculated over 10 work orders. The combination of type of work with the selected equipment units results in eight scenarios, shown in Table 3.

Table 3; Scenarios evaluation managing maintenance process

	Type of work	
Equipment unit	**Preventive**	**Corrective**
G280 ([redacted])	Scenario 1	Scenario 2
G500 ([redacted])	Scenario 3	Scenario 4
V260 ([redacted])	Scenario 5	Scenario 6
V020 ([redacted])	Scenario 7	Scenario 8

Below the eight scenarios are shortly explained. Besides, in Figure 1 of this report the location of the equipment units in the production process is shown by red circles. To each scenario a set of work orders is related, in appendix E the set of work orders for each scenario can be found.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

7.2.2 Measure: Current state maintenance process and equipment performance

In this sub section, the current state of the maintenance process and the equipment performance of the Zor-f plant for all eight scenarios, is quantified. For each Performance Indicator of the PMS in each scenario the current value of the Performance Indicator is defined. The defined values are based on *the functional location, priority, description, scheduled finish date, actual finish date, total planned cost and total actual cost* of the executed work orders in 2016 related to each scenario. Besides, the values are based on assumptions. Assumptions are needed, since currently not all required data is available to quantify the current state of each Performance Indicator. The assumptions are made by the researcher of this project. Next, the assumptions are verified by the maintenance manager ([redacted]), maintenance supervisor ([redacted]) and technicians of the Zor-f plant. Below for each Performance Indicator in each scenario the current value is given and there is explained how this value is obtained.

Performance Indicator Mean Time Between Failure (MTBF)

In order to define the current value of the Performance Indicator *Mean Time Between Failure* for all corrective scenarios, the steps mentioned below need to be performed. These steps are based on a part of the formulas from sub section 6.2.1.

$$c(a,b) = \begin{cases} a \text{ , if } b = 0 \\ \frac{a}{b} \text{, otherwise} \end{cases} \qquad (7.1)$$

With:

$\boldsymbol{a}$ = Loading time of equipment unit $\boldsymbol{i}$ [days]
$\boldsymbol{b}$ = Number of failure moments of equipment unit $\boldsymbol{i}$ [#]
$\boldsymbol{c}$ = Mean time between failure of equipment unit $\boldsymbol{i}$ [days]
$\boldsymbol{i}$ = Equipment unit

- First, *the loading time of the equipment unit* related to a scenario is determined. Since, the Zor-f plant has a continue production process and produces 24 for 7, such as mentioned in Chapter 1 and 4, it is assumed that *the loading time of the equipment units* G280, G500, V260 and V020 is equal to 365 days. See Table 4, second column.

- Next, *the number of failures moments of the equipment unit* related to a scenario is determined. For this evaluation only equipment failure that has impact on the production process is included. At the Zor-f plant the work orders with priority 0 and 1 need to be solved as soon as possible, such as mentioned in section 4.5. Due to the fact that the equipment failure moments related to these work order have direct impact on the production process. So, *the number of failure moments of an equipment unit* is equal to the number of corrective work orders with priority 0 and 1. See Table 4, third column.

- At last, *the loading time of an equipment* is divided by *the number of failure moments of an equipment unit,* in order to obtain the *Mean Time Between Failure* for a corrective scenario. See Table 4, last column.

Corrective and preventive maintenance together determine the equipment performance, so determine also together the *Mean Time Between Failure.* For preventive scenarios the *Mean Time Between Failure* cannot be determined, because equipment failure is only visible as corrective maintenance. Therefore is assumed that the *Mean Time Between Failure* of a corrective scenario is equal to the *Mean Time Between Failure* of the preventive scenario for the same equipment unit. See Table 4.

Table 4 shows the current values of the Performance Indicator *Mean Time Between Failure* for all scenarios. The table shows that the scenarios related to the G280 have the largest *Mean Time Between Failure* currently. In addition, the table shows that the scenarios related to the V260 have the lowest *Mean Time Between Failure* currently.

Table 4; Current state Performance Indicator Mean Time Between Failure

Scenarios	a [days]	b [#]	c [days]
1; Preventive work G280	[redacted]	[redacted]	73
2; Corrective work G280	[redacted]	[redacted]	73
3; Preventive work G500	[redacted]	[redacted]	41
4; Corrective work G500	[redacted]	[redacted]	41
5; Preventive work V260	[redacted]	[redacted]	24
6; Corrective work V260	[redacted]	[redacted]	24
7; Preventive work V020	[redacted]	[redacted]	46
8; Corrective work V020	[redacted]	[redacted]	46

Performance Indicator Mean Time To Repair (MTTR)

In order to define the current value of the Performance Indicator *Mean Time To Repair* for all corrective scenarios, the steps mentioned below need to be performed. These steps are based on a part of the formulas from sub section 6.2.2.

$$f(e,m) = \begin{cases} 0 \text{, if } m = 0 \\ \frac{\sum_{j \in J} e}{m} \text{, otherwise} \end{cases} \quad (7.2)$$

With:

$\boldsymbol{e}$ = Repair time of failure moment $\boldsymbol{j}$ of equipment unit $\boldsymbol{i}$ [hours]
$\boldsymbol{f}$ = Mean time to repair equipment unit $\boldsymbol{i}$ [hours]
$\boldsymbol{i}$ = Equipment unit
$\boldsymbol{m}$ = Number of failure moments of equipment unit $\boldsymbol{i}$ [#]
$\boldsymbol{j}$ = Equipment failure moment of equipment unit $\boldsymbol{i}$
$\boldsymbol{J}$ = Set of failure moments of equipment units $\boldsymbol{i}$

- First, *the number of failure moments of an equipment unit* related to a scenario is determined. This is already determined for the previous Performance Indicator and can be found in the third column of Table 5.

- Next, *the repair time of all failure moments of an equipment unit* is defined. First, for each failure moment of an equipment unit is estimated the repair time. This is done by a technician. Next, the repair time of all failure moments of an equipment unit is added. See Table 5 second column.

- At last, *repair time of all equipment failure moments of an equipment unit* is divided by *the number of equipment failure moments of an equipment unit,* in order to obtain the *Mean Time To Repair* for a corrective scenario. See the last column of Table 5.

Mean Time To Repair cannot be determined for preventive scenarios, because repair activities are only related to corrective maintenance. Therefore, the preventive scenarios cannot be provided with a current value. See Table 5.

Table 5 shows the current values of the Performance Indicator *Mean Time To Repair* for all corrective scenarios. The tables shows that the corrective scenario related to the G280 have the largest *Mean Time To Repair* currently, followed by the corrective scenarios related to the G500, V260 and V020.

Table 5; Current state Performance Indicator Mean Time To Repair

Scenarios	$\sum_{j \in J} e$ [hours]	m [#]	f [hours]
1; Preventive work G280	[redacted]	[redacted]	-
2; Corrective work G280	[redacted]	[redacted]	8
3; Preventive work G500	[redacted]	[redacted]	-
4; Corrective work G500	[redacted]	[redacted]	4
5; Preventive work V260	[redacted]	[redacted]	-
6; Corrective work V260	[redacted]	[redacted]	3
7; Preventive work V020	[redacted]	[redacted]	-
8; Corrective work V020	[redacted]	[redacted]	1

Performance Indicator Direct maintenance costs

In order to define the current value of the Performance Indicator *Direct maintenance cost,* the formula from sub section 6.2.4. can be used. For the corrective scenarios the parameter *k* will be put on zero. For the preventive scenarios the parameter *h* will be put on zero.

$$l\,(h,k) = h + k \tag{7.3}$$

$\boldsymbol{l}$ = Total direct maintenance cost [euros]
$\boldsymbol{h}$ = Total cost of corrective maintenance activities [euros]
$\boldsymbol{k}$ = Total cost of preventive and predictive maintenance activities [euros]

Both for the preventive as for the corrective scenarios *the total direct maintenance cost* is equal to the sum of *the total actual cost* of all work orders related to a scenario. The current values of the Performance Indicator *total direct maintenance cost* for all eight scenarios are shown in Table 6. The table shows that often the *total direct maintenance cost* for preventive scenarios is lower than the *total direct maintenance cost* for corrective scenarios, expect for the scenarios related to the G280.

Table 6; Current state Performance Indicator direct maintenance cost

Scenarios	l X1000 [euros]
1; Preventive work G280	[redacted]
2; Corrective work G280	[redacted]
3; Preventive work G500	[redacted]
4; Corrective work G500	[redacted]
5; Preventive work V260	[redacted]
6; Corrective work V260	[redacted]
7; Preventive work V020	[redacted]
8; Corrective work V020	[redacted]

Performance Indicator Labor estimation

In order to define the current value of the Performance Indicator *Labor estimation* for all scenarios, the steps mentioned below need to be performed. These steps are based on the formulas from sub section 6.2.4.

$$r(p,q) = \begin{cases} 1, \text{ if } p - 10\% < q < p + 10\% \\ 0, \text{ otherwise} \end{cases} \tag{7.4}$$

$$s(r,n) = \frac{\sum_{i \in I} r}{n} * 100\% \tag{7.5}$$

With:

p = Estimated labor hours of work order i [hours]
q = Actual labor hours of work order i [hours]
r= The number of work orders with an accurate labor estimation [#]
s= % work orders with an accurate labor estimation [%]
n = Total number of executed work orders [#]
i= Executed work order
I= Set of executed work orders

- First, *the number of work orders with an accurate labor estimation* is determined. Since, the estimated and actual labor hours are not available per work order, *the total planned cost* and *the total actual cost* of a work order are used. In order to use *the total planned cost* and *the total actual cost* of a work order, some assumptions need to be made. The first assumption is that 50% of the cost of a work order is related to labor. So, the amount of labor is represented by half of the planned cost and by half of the actual cost (Appendix A, [redacted]). The second assumption is that most of the additional costs are related to labor and not to material or third parties. This is, because the cost of material and third-parties can be estimated accurately in advance. This means the estimated labor hours of a work order can be represented by half of the total planned cost of a work order and that the actual labor can be represented by half of the total actual cost of a work order. Based on this*, the number of work orders with an accurate labor estimation* is defined. A work order is correctly estimated if the actual labor hours are within a range from minus 10% to plus 10% of the estimated labor hours. If *the total planned cost* and *the total actual cost* of a work order are used, this means a work order is correctly estimated if *the total actual cost* of a work order are within a range from minus 10% to plus 10% of the *total planned cost* of a work order. *The number of work orders with an accurate labor estimation* per scenario is shown in Table 7 in the second column.

- Next, *the number of executed work orders* is determined. Shown in Table 7 in the third column.

- At last, *the number of work orders with an accurate labor estimation* is divided by the *total number of executed work orders*, in order to obtain the *percentage work orders with an accurate labor estimation* for a scenario. Shown in Table 7 in the last column.

Table 7 shows the current values of the Performance Indicator *Labor estimation* for all scenarios. The table shows that the labor estimation for the scenario related to the G280 and V020 is relative well. Besides, the table shows that the labor estimation related to the preventive scenarios is better than the labor estimation related to corrective scenarios, except for the scenarios related to the G280.

Table 7; Current state Performance Indictor labor estimation

Scenarios	$\sum_{i \in I} r$ [#]	n [#]	s [%]
1; Preventive work G280	18	88	20
2; Corrective work G280	6	19	32
3; Preventive work G500	3	48	6
4; Corrective work G500	0	26	0
5; Preventive work V260	10	75	13
6; Corrective work V260	3	40	8
7; Preventive work V020	20	51	39
8; Corrective work V020	7	31	23

Performance Indicator Man-power efficiency

In order to define the current value of the Performance Indicator *Man-power* for all scenarios, the formulas from sub section 6.2.5 cannot be used. This is caused by the fact that these formulas are too detailed. Therefore, another way is used to define the current values of this Performance Indicator. This way is shortly described below.

For all scenarios a man-power efficiency of 44% is used as starting point. This percentage is mentioned in sub section 6.2.5. Next, is defined if the man-power efficiency is lower or high than 44% in a scenario. If the man-power efficiency is lower or high than 44% in a specific scenario depends on the waiting time during execution of work orders and the difficulty of the execution of work orders.

Table 8 shows the current values of the Performance Indicator *Man-power efficiency* for all scenarios. The table shows that the man-power efficiency for the preventive scenarios is higher than the man-power efficiency for the corrective scenarios.

Table 8; Current state Performance Indicator man-power efficiency

Scenarios	Man-power efficiency [%]
1; Preventive work G280	50
2; Corrective work G280	20
3; Preventive work G500	60
4; Corrective work G500	15
5; Preventive work V260	50
6; Corrective work V260	15
7; Preventive work V020	45
8; Corrective work V020	20

Performance Indicator Rework

In order to define the current value of the Performance Indicator *rework* for the corrective scenarios the steps mentioned below need to be performed. These steps are based on the formulas from sub section 6.2.6.

$$z(y) = \begin{cases} 1, \text{if } y = \text{rework} \\ 0, \text{otherwise} \end{cases} \quad (7.6)$$

$$\alpha(z,n) = \frac{\sum_{i \in I} z}{n} * 100\% \quad (7.7)$$

With:

$\boldsymbol{y}$ = Work order $\boldsymbol{i}$
$\boldsymbol{z}$ = The number of work orders that is rework [#]
$\boldsymbol{\alpha}$ = % executed rework orders of the set of executed work orders [%]
$\boldsymbol{n}$ = Total number of executed work orders [#]
$\boldsymbol{i}$= Executed work order
$\boldsymbol{I}$= Set of executed work orders

- First, *the number of work orders that is rework* needs to be defined. In this evaluation is assumed that a work order is rework if for the second time a corrective work order is made for the same functional location in a short time. So, work orders meet this assumption are rework orders and determine *the number of work orders that is rework*. Shown Table 9 in the second column.

- Next, *the total number of executed work orders* is defined. Shown in Table 9 in the third column.

- At last, the *number of rework orders* is divided by *the total number of executed work orders,* in order to obtain the *percentage executed work order that is rework of the total executed work orders.* Shown in Table 9 in column 4.

Both corrective as preventive maintenance can cause rework. Therefore, they determine together the current value of the Performance Indicator *Rework.* However, for preventive scenarios *rework* cannot determined, because rework results always in equipment failure what is related to corrective maintenance. Therefore, is assumed that the value of the Performance Indicator *rework* of a corrective scenario of an equipment units is equal to the value of the Performance Indicator *rework* of the preventive scenario of the same equipment unit. See Table 9.

Table 9 shows the current values of the Performance Indicator *rework* for all scenarios. The tables shows that scenarios related to the V260 have more rework than the scenarios related to other equipment units.

Table 9; Current state Performance Indicator rework

Scenarios	$\sum_{i \in I} z$ [#]	n [#]	α [%]
1; Preventive work G280	[redacted]	[redacted]	5
2; Corrective work G280	[redacted]	[redacted]	5
3; Preventive work G500	[redacted]	[redacted]	4
4; Corrective work G500	[redacted]	[redacted]	4
5; Preventive work V260	[redacted]	[redacted]	13
6; Corrective work V260	[redacted]	[redacted]	13
7; Preventive work V020	[redacted]	[redacted]	6
8; Corrective work V020	[redacted]	[redacted]	6

Performance Indicator Schedule compliance

In order to define the current state of the Performance Indicator *schedule compliance* for all eight scenarios the steps mentioned below need to be performed. These steps are based on the formulas from sub section 6.2.7.

$$\delta(\beta, \gamma) = \begin{cases} 1, \text{if } \beta = \gamma \\ 0, \text{otherwise} \end{cases} \tag{7.8}$$

$$\varepsilon(\delta, n) = \frac{\sum_{i \in I} \delta}{n} * 100\% \tag{7.9}$$

With:

β = Scheduled period of work order execution of work order i [date]
γ = Actual executed period of work execution of work order i [date]
δ = The number of work orders executed in their scheduled period [#]
ε = % work orders executed in their scheduled period of the set of executed work orders [%]
n = Total number of executed work orders [#]
i= Executed work order
I= Set of executed work orders

- First, *the number of work orders executed in their scheduled period* is determined. A work order is executed in its scheduled period if *the actual finish date* of a work order is before *the scheduled finish date* of a work order. *The number of work order executed in their scheduled period* is shown in the second column of Table 10.

- Next, *the total number of executed work orders* is determined. Shown in the third column of Table 10.

- At last, *the number of work orders executed in their scheduled period* is divided by *the total number of executed work order*, in order to obtain *the percentage work orders executed their scheduled.* Shown in Table 10 in the fourth column.

Table 10 shows the current values of the Performance Indicator *schedule compliance* for all scenarios. The table shows that for the preventive scenarios more work orders are executed in their scheduled period than for the corrective scenarios currently.

Table 10; Current state Performance Indicator Schedule compliance

Scenarios	$\sum_{i \in I} \delta$ [#]	n [#]	ε [%]
1; Preventive work G280	82	88	93
2; Corrective work G280	17	19	89
3; Preventive work G500	42	48	77
4; Corrective work G500	18	26	69
5; Preventive work V260	71	75	95
6; Corrective work V260	26	40	65
7; Preventive work V020	44	51	86
8; Corrective work V020	22	31	71

7.2.3 Improve: Expected future state maintenance process and equipment performance

In the previous sub section the current state of the maintenance process and equipment performance is quantified for all scenarios. In this sub section the expected future state of the maintenance process and equipment performance is quantified for all scenarios. This expected future state is the state of the maintenance process and equipment performance after using the PMS for managing the maintenance process, for an infinite number of improvement cycles. The infinite number of improvements cycles is equal to the number of improvement cycles that is needed to obtain an improvement that is no longer measurable.

In order to quantify the expected future state of the maintenance process and equipment performance separate interviews are done with the maintenance manager of the Zor-f plant ([redacted]), the maintenance supervisor of the Zor-f plant ([redacted]) and the contract manager from DSC ([redacted]). They are selected, because they have to use the PMS in the future. In each interview the three steps mentioned below are performed for each scenario. This means the steps mentioned below are executed for all eight scenarios in each interview. The first step is that, a list with the description of all the work orders in 2016 related to a scenario, is shown to the respondent. This list for each scenario can be found in Appendix E. The second step is that the process Performance Indicators (In Table 11 these are Performance Indicators 4 to 7) are provided with a value. They are provided with a value by asking the question: “What will be the expected future value of Performance Indicator X in scenario Z after managing the maintenance process, by using the PMS, for an infinite number of improvement cycles, if the current value of Performance Indicator X will be Y in scenario Z?” At last, the same question, as mentioned above, is asked to the respondent, only then for the result Performance Indicators (In Table 11 these are Performance Indicators 1 to 3). The results of the steps mentioned above for all scenarios and for all three interviews are presented in Appendix F. Finally, the values provided by the three respondents are averaged.

Table 11 shows the results of the process described above. The table shows the expected future values of all Performance Indicators in each scenario. In addition, the table shows the current values of all Performance Indicators in each scenario, defined in the previous sub section. The expected future values given in the table need to be interpreted for example as if the current value of the Performance Indicator *Labor estimation* will be 20 % for the preventive work G280 scenario, after, using the PMS for managing the maintenance process for an infinite number of improvement cycles, the expected future value of the Performance Indicator *Labor estimation* will be 60 % for the preventive work G280 scenario.

Table 11 shows that for the most Performance Indicators the scenarios relative to each other are not changed a lot, if the current state is compared with the excepted future state. Only remarkable is that for the Performance Indicator *Mean Time Between Failure* the value of the preventive scenario of an equipment unit and the value of the corrective scenario of the same equipment unit are no longer equal to each other. This is the case for all equipment units.

Table 11; Current and expected future state maintenance process and equipment performance of the Zor-f plant

			Scenarios															
			1; Preventive work G280		2; Corrective work G280		3; Preventive work G500		4; Corrective work G500		5; Preventive work V260		6; Corrective work V260		7; Preventive work V020		8; Corrective work V020	
			Current	Future	Current	Future	Current	Future	Current	Future	Current	Future	Current	Future	Current	Future	Current	Future
Performance Indicators	1	**MTBF** [days]	73	84	73	93	41	55	41	60	24	41	24	43	46	55	46	53
	2	**MTTR** [hours]	-	-	8	6	-	-	4	4	-	-	3	3	-	-	1	1
	3	**Maintenance costs x** 1000 [€]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	4	**Labor estimation** [%]	20	60	32	50	6	59	0	43	13	80	8	57	39	80	23	57
	5	**Man-power efficiency** [%]	50	62	20	43	60	63	15	53	50	67	15	42	45	60	20	47
	6	**Rework** [%]	5	3	5	4	4	3	4	3	13	7	13	9	6	4	6	4
	7	**Schedule compliance** [%]	93	94	89	91	77	87	69	81	95	95	65	82	86	95	71	82

7.2.4 Control: Potential improvement maintenance process and equipment performance

In this section is evaluated if using the new PMS for managing the maintenance process, has the potential to improve the maintenance process and equipment performance of the Zor-f plant. In Table 12 is shown the potential improvement of the maintenance process and equipment performance of the Zor-f plant. The green cells show Performance Indicators have the potential to improve in a scenario. The table shows the potential improvement in absolute value for all Performance Indicators. This is the expected future value of a Performance Indicator minus the current value of a Performance Indicator. For example the Performance Indicator *Mean Time Between Failure* in scenario 1 increases by 11 days and the Performance Indicator *Rework* in scenario 1 decreases by 2 %. Besides, the table shows the potential improvement as a percentage for the first three Performance Indicators. This is the expected future value of a Performance Indicator minus the current value of a Performance Indicator, divided by the current value of a Performance Indicator. For example the *Mean Time Between Failure* in scenario 1 increases by 11 days, this is equal to an increase of 15%. For the second, third and sixth Performance Indicator a decrease is an improvement and for the other Performance Indicators an increase is an improvement.

Table 12; Potential improvement maintenance process and equipment performance of the Zor-f plant

			Scenarios							
			1; Preventive work G280	2; Corrective work G280	3; Preventive work G500	4; Corrective work G500	5; Preventive work V260	6; Corrective work V260	7; Preventive work V020	8; Corrective work V020
Performance Indicators	1	**Mean Time Between Failure** [days]	+ 11 (15%)	+ 20 (27%)	+ 14 (34%)	+ 19 (46%)	+ 17 (71%)	+ 19 (79%)	+ 9 (20%)	+ 7 (20%)
	2	**Mean Time To repair** [hours]	-	-2 (-25%)	-	0 (0%)	-	0 (0%)	-	0 (0%)
	3	**Direct maintenance costs** x 1000 [euros]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	4	**Labor estimation** [%]	+ 40	+ 19	+ 53	+ 43	+ 67	+ 49	+ 41	+ 34
	5	**Man-power efficiency** [%]	+ 12	+ 23	+ 3	+ 38	+ 17	+ 27	+ 15	+ 27
	6	**Rework** [%]	-2	-1	-1	-1	-6	-4	-2	-2
	7	**Schedule compliance** [%]	+ 1	+ 2	+ 10	+ 12	0	+ 17	+ 9	+ 11

The Performance Indicators *direct maintenance cost, labor estimation, man-power efficiency, rework and schedule compliance* define together the performance of the maintenance process of the Zor-f plant. Table 12 shows that these Performance Indicators have the potential to improve in nearly all scenarios. Based on this can be concluded that using the PMS for managing the maintenance process, has the potential to improve the maintenance process of the Zor-f plant in all eight scenarios. It can be assumed that this will be also the case for other scenarios. So, it can be concluded in general that using the new PMS for managing the maintenance process, has the potential to improve the maintenance process of the Zor-f plant.

The Performance Indicators *Mean Time Between Failure* and *Mean Time Between Repair* define together the equipment performance. Table 12 shows that mainly the Performance Indicator *Mean Time To Repair* has the potential to improve in all eight scenarios. Based on this can be concluded that using the new PMS for managing the maintenance process, has potential to improve the equipment performance of the Zor-f plant in all eight scenarios. It can be assumed that this will be also the case for other scenarios. So, it can be concluded in general that using the new PMS for managing the maintenance process, has the potential to improve the equipment performance of the Zor-f plant.

Question 8: Has, using the performance measurement system for managing the maintenance process of the Zor-f plant, the potential to improve the maintenance process and equipment performance of the Zor-f plant?

Yes, using the performance measurement system designed in this project for managing the maintenance process, has the potential to improve the maintenance process and equipment performance of the Zor-f plant.

7.3 Evaluation managing the Performance Based Contract between DSC and DSP

In this section is evaluated if using the new PMS for managing the PBC between DSC and DSP, has the potential to stimulate DSC to carry out an effective and efficient maintenance process. Besides, is evaluated if using the new PMS for managing the PBC between DSC and DSP, aligns the objectives of DSC and DSP. Since, the Performance Indicator *Mean Time To Repair* is the only Performance Indicator of the PMS that can be used to manage the PBC the sentence mentioned above can be also formulated as: if using the Performance Indicator *Mean Time To Repair* to manage the PBC between DSC and DSP*,* has the potential to stimulate DSC to carry out an effective & efficient maintenance process and aligns the objectives of DSC & DSP. This evaluation is performed by doing a SWOT-analysis both from the viewpoint of the customer, DSP, as from the viewpoint of the contractor, DSC. A SWOT-analysis is an often used method to show Strengths, Weaknesses, Opportunities and Threats of an organization (managementmodellensite.nl, n.d.). In the context of this project Strengths can be interpreted as a positive point and Weaknesses can be interpreted as a negative point if the Performance Indicator *Mean Time To Repair (MTTR)* is used for managing the PBC. The Strengths and Weaknesses are viewpoint-independent. The Opportunities and Threats can be interpreted as the consequences of the Strengths and Weaknesses. The Opportunities and Threats are viewpoint-dependent.

The SWOT-analysis is performed by a semi-structured interview with the plant manager of the Zor-f plant [redacted]) and by a semi-structured interview with the contract manager from DSC ([redacted]), because they are responsible for the PBC from the side of the customer and from the side of the contractor. This way a complete overview is created. Both interviews are started with the question: “What are strengths and weaknesses, if the PBC is managed by using the Performance Indicator *Mean Time To Repair?”* To support the thought process of the respondents some examples of strengths and weaknesses are given first by the researcher of this project. Next, is asked the question: “What are the consequences of the strengths and weaknesses mentioned before for DSC?” in the case of [redacted] [redacted] and “What are the consequences of the strengths and weaknesses mentioned before for DSP?” in the case of [redacted].

The results of the process described above are shown in Figure 23. The figures shows the strengths, weaknesses, opportunities and threats, if the Performance Indicator *Mean Time To Repair* is used to manage the PBC between DSC and DSP. The figure shows that four strengths and four weaknesses are identified. Besides, the figure shows that three opportunities are identified, two from the viewpoint of DSP and one from the viewpoint of DSC & DSP. The figures shows also that three threats are identified, one from the viewpoint of DSP and two from the viewpoint of DSC. Below the points mentioned in Figure 23 are discussed in more detail.

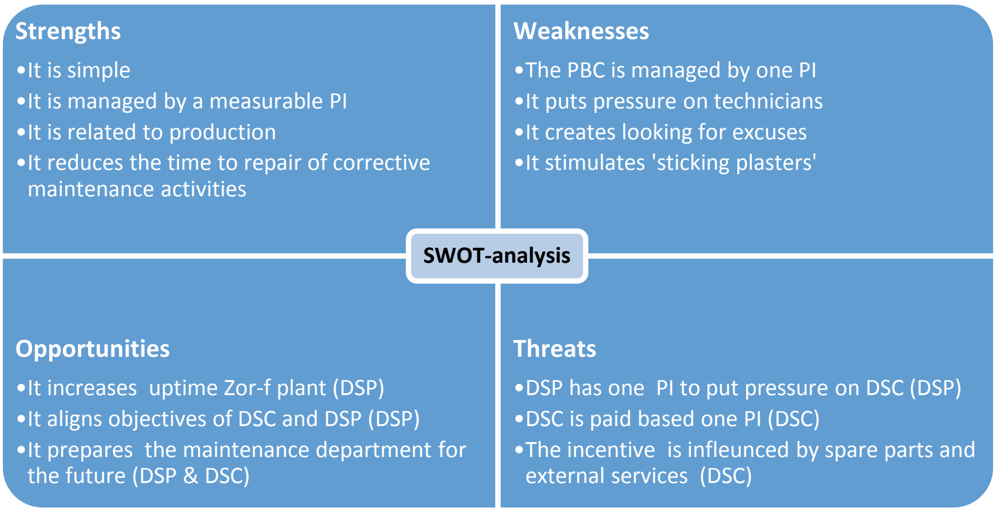

Figure 23; SWOT-analysis

- **Strengths**
  There are four strengths if the Performance Indictor *Mean Time To Repair* is used to manage the PBC between DSC and DSP*.* First, it is simple because DSC and DSP have to manage one Performance Indicator. Besides, it is simple because everyone understands what *Mean Time To Repair* means. Everyone understands a *Mean Time To Repair* of 2 hours is better than a *Mean Time To Repair* of 4 hours. Secondly, a measurable Performance Indicator is used to manage the PBC. This is positive, because this way it is not possible to call into question the incentive. Thirdly, a Performance Indicator related to production is used to manage the PBC. *Mean Time To Repair* is related to production, because it determines the availability of equipment. At last, using the Performance Indicator *Mean Time To Repair* to manage the PBC, will reduce the time to repair of corrective maintenance activities. Since, this results in a high incentive for DSC.

- **Weaknesses**
  There are four weaknesses if the Performance Indicator *Mean Time To Repair* is used to manage the PBC between DSC and DSP*.* Firstly, if the Performance Indicator *Mean Time To Repair* is used to manage the PBC, the incentive is defined by one Performance Indicator. A consequence of this could be that a not balanced overview of the actual performance is created for defining the incentive. Secondly, if the Performance Indicator *Mean Time To Repair* is used to manage the PBC, it puts pressure on technicians. If a technician does not execute his job well, it can have directly influence on the incentive. As a result technicians will get a large responsibility. Due to this large responsibility, technicians can try to avoid this large responsibility by avoiding the execution of corrective maintenance activities. Thirdly, if the Performance Indicator *Mean Time To Repair* is used to manage the PBC, it creates looking for excuses if the *Mean Time To Repair* is high. As a result DSC can blame other people or organizations. At last, if the Performance Indicator *Mean Time To Repair* is used to manage the PBC, it stimulates 'sticking plasters' during the execution of corrective maintenance activities. This means if equipment fails, DSC wants to solve as soon as possible the equipment failure, in order to minimize the *Mean Time To Repair*. Due to this, long term solutions will be not considered during the execution of corrective maintenance activities. As a result, maybe not the right things are done during the execution of corrective maintenance activities, in order to increase the uptime of the equipment in the long term.

- **Opportunities**
  The strengths result in three opportunities. Firstly, if the Performance Indicator *Mean Time To Repair* is used to manage the PBC the uptime of the Zor-f plant will increase, because the *Mean Time To Repair* will reduce. This is caused by the fact that DSC wants a high incentive. This is an opportunity for DSP. Secondly, if the Performance Indicator *Mean Time To Repair* is used to manage the PBC the objectives of DSC and DSP will be aligned. DSC wants a high incentive. As a result the *Mean Time To Repair* will reduce*.* Due to this*,* the uptime of the Zor-f plant will increase. A high uptime of the Zor-f plant is an important objective of DSP. So, the objective of DSC to receive a high incentive contributes to the objective of DSP. This is an opportunity for DSP. At last, if the Performance Indicator *Mean Time To Repair* is used to manage the PBC it prepares the maintenance department for the future, because *Mean Time To Repair* will be more and more important at the Zor-f plant. This is caused by the fact that the Zor-f plant will be expanded in 2017. This is an opportunity both for DSC as DSP.

- **Threats**
  The weaknesses result in three threats. Firstly, if the Performance Indicator *Mean Time To Repair* is used to manage the PBC DSP has one Performance Indicator which they can used to put pressure on DSC. This is a threat for DSP, because this way it is difficult for DSP to manage their contractor. Secondly, if the Performance Indicator *Mean Time To Repair* is used to manage the PBC*,* the incentive is also defined by one Performance Indicator. This means DSC is paid based on the performance on

one Performance Indicator. For DSC this is a threat, because they can receive a low incentive while they perform well in general, except for one Performance Indicator. At last, if the Performance Indicator *Mean Time To Repair* is used to manage the PBC, the incentive of the PBC can be influenced by spare parts or external services. This is a threat for DSC, because DSC can receive a low incentive without being responsible for the bad performance.

Based on the Strengths, Weaknesses, Opportunities and Threats from the SWOT-analysis can be concluded if using the Performance Indicator *Mean Time To Repair* for managing the PBC between DSC & DSP, has the potential to stimulate DSC to carry out an effective & efficient maintenance process and aligns the objectives of DSC & DSP. Since, the Performance Indicator *Mean Time To Repair* is the only Performance Indicator of the PMS that can be used to manage the PBC, the sentence mentioned above can be also formulated as: if using the PMS for managing the PBC between DSC & DSP, has the potential to stimulate DSC to carry out an effective & efficient maintenance process and aligns the objectives of DSC & DSP.

In Chapter 1 'an effective maintenance process' is defined as a maintenance process that executes the right things and executes these things in the right way, in order to increase the uptime of equipment. The SWOT-analysis shows that the uptime of the Zor-f plant will increase, because the corrective maintenance activities will be executed in such a way that the time to repair of these maintenance activities is as low as possible. So, the corrective maintenance activities are executed in the right way. Besides, the SWOT-analysis shows that in order to increase the uptime of equipment in the long-term maybe not the right things are executed during the execution of corrective maintenance activities. However, this is not a problem because the right things, the long-term solutions, can be executed later on. For example during a planned production stop for preventive maintenance. For this reason the uptime of equipment can be also increase in the long term. Based on this can be concluded that using the new PMS for managing the PBC between DSC and DSP, has the potential to stimulate DSC to carry out an effective maintenance process.

In Chapter 1 'an efficient maintenance process' is defined as a maintenance process that increases the uptime of equipment, with minimal effort, so with minimal time and cost. The SWOT-analysis shows that the uptime of the Zor-f plant will increase. Besides, the SWOT-analysis shows that the corrective maintenance activities will be executed in such a way that the time to repair of these maintenance activities is as low as possible. So, the corrective maintenance activities are executed with minimal time. Based on the definition and the SWOT-analysis can be concluded that using the new PMS for managing the PBC between DSC and DSP, has the potential to stimulate DSC to carry out an efficient maintenance process.

In addition, based on the SWOT-analysis can be concluded that using the new PMS for managing the PBC between DSC and DSP, aligns the objectives of DSC and DSP.

To summarize, using the new PMS for managing the PBC between DSC and DSP, has the potential to stimulate DSC to carry out an effective and efficient maintenance process. Besides, using the new PMS for managing the PBC between DSC and DSP, aligns the objectives of DSC and DSP.

Question 9: *Has, using the performance measurement system for managing the Performance Based Contract between DSC and DSP, the potential to stimulate DSC to carry out an effective and efficient maintenance process?"*

Yes, using the performance measurement system designed in this project for managing the Performance Based Contract between DSC and DSP, has the potential to stimulate DSC to carry out an effective and efficient maintenance process.

Question 10: *If the performance measurement system is used to manage the Performance Based Contract between DSC and DSP, are the objectives of DSC and DSP aligned?*

Yes, if the performance measurement system designed in this project is used to manage the Performance Based Contract between DSC and DSP, the objectives of DSC and DSP are aligned.

8 Implementation plan of the Performance Measurement System

This chapter discusses the implementation of the Performance Measurement System (PMS) at the Zor-f plant. Here, a distinction is made between the implementation of the Performance Indicators of the PMS and the implementation of the PMS itself.

8.1 Implementation of the Performance Indicators

Below is discussed per Performance Indicator of the PMS what needs to be done in order to implement the Performance Indicator at the Zor-f plant.

- **Mean Time Between Failure**
  Before the Performance Indicator Mean Time Between Failure can be implemented, it is needed to decide which equipment units are used in order to calculate this Performance Indicator. For example are used all equipment units or only the equipment units in the bottle neck of the production process. Next, a program needs to be installed on the selected equipment units. This program that should register the equipment failures and should be connected to existing programs. Besides, the scheduled operation time needs to be defined for the selected equipment units.

- **Mean Time To Repair**
  Before the Performance Indicator Mean Time To Repair can be implemented, it is needed to decide which equipment units are used to calculate this Performance Indicator. Next, a program needs to be installed on the selected equipment units. This program that should register the equipment failures and should be connected to existing programs.

- **Direct maintenance cost**
  This Performance Indicator can be implemented right away, because currently this Performance Indicator is already used. So, no addition actions need to be taken in order to implement this Performance Indicator at the Zor-f plant.

- **Labor estimation**
  In order to implement this Performance Indicator it is needed to register the estimated labor hours and the actual labor hours of work orders in an existing program.

- **Man-power efficiency**
  Before this Performance Indicator can be implemented it is needed to decide which maintenance activities are used in order to define the man-power efficiency at the Zor-f plant. Since, it is not feasible to define the man-power efficiency of all maintenance activities. The selected maintenance activities should give a good overview of the man-power efficiency of the most maintenance activities at the Zor-f plant. Besides, a tool needs to be selected that supports man-power efficiency measurements and a program needs to be selected that registers the data of the man-power efficiency measurements.

- **Rework**
  In order to implement this Performance Indicator it is needed to develop a system that recognizes if a work order is a rework order. Next, it is needed to register the recognized rework orders in an existing program.

- **Schedule compliance**
  This Performance Indicator can be implemented right away, because the data needed for the calculation of this Performance Indicator is available. So, no addition actions need to be taken in order to implement this Performance Indicator at the Zor-f plant.

8.2 Implementation of the Performance Measurement System

In addition to the implementation of the Performance Indicators of the PMS, the PMS itself needs to be implemented. In this section is discussed what needs to be done in order to implement the PMS at the Zor-f plant. This is described by using Deming's (1982) cycle. This method is often used qualitative approach to improve processes. The cycle consists of the process steps Plan, Do, Check and Act (Deming, 1982). Plan stands for plan the process, Do stands for act the process, Check stands for measure the results and Act stands for act on the gap between the intended goals and the achieved results (Senapati, 2004). In Figure 24 Deming's cycle is applied on the implementation of the PMS. Below all the four process steps will be shortly discussed. By performing these process steps the PMS will be successfully implemented at the Zor-f plant.

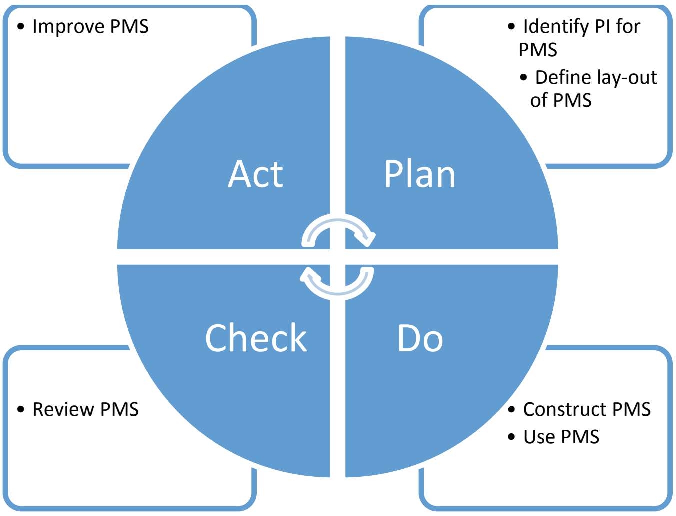

Figure 24; Implementation Performance Measurement System

First process step: Plan
The first process step consists of two activities, identification of Performance Indicators for the PMS and defining the lay-out of the PMS. The first activity is done in this project. The second activity needs to be done by consulting an experts on KPI dashboards. This expert can advise on the presentation of the Performance Indicators, for example if the Performance Indicators need to be presented by graphs or by dashboard meters, if filters on the data are needed in order to analyze the Performance Indicators, if all information needs to be visible or not, etc.

Second process step: Do
The second process step consists also of two activities. First, the PMS needs to be constructed. This needs to be done by a software developer. The software developer has to connect all the programs that provide data for the Performance Indicators to the program in which the PMS is constructed. Besides, the software developer needs to program the lay-out of the PMS that is recommended by the expert on KPI dashboards.

Next, the PMS needs to be used. This can be also described by using Deming's cycle. Shown in Figure 25. First, the targets of the Performance Indicators need to be defined. Next, the Performance Indicators need to be measured. After measuring the Performance Indicators, it is needed to check if the Performance Indicators have achieved their targets. At last, if the targets are not achieved improvement actions need to be taken in order to improve the performance of the Performance Indicators.

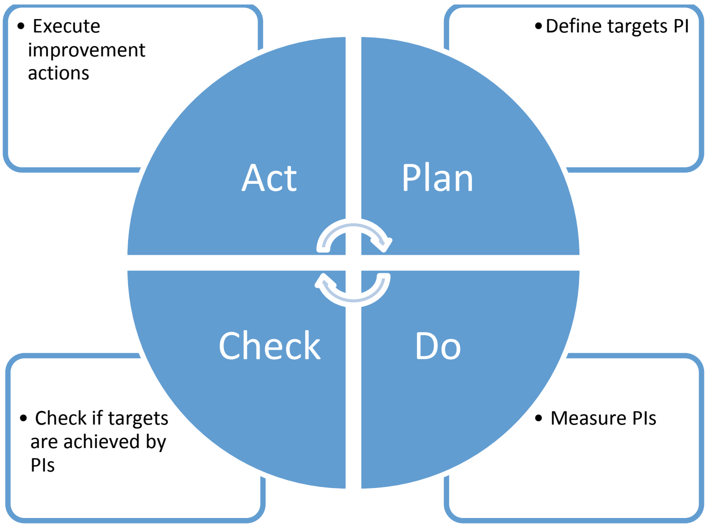

Figure 25; Use Performance Measurement System

Third process step: Check
Next, the PMS needs to be reviewed. This review consists of two parts. First, there needs to be reviewed if using the PMS for managing the maintenance process of the Zor-f plant improves the maintenance process and the equipment performance of the Zor-f plant. Besides, there needs to be reviewed if using the PMS for managing the PBC between DSC and DSP stimulates DSC to carry out an effective & efficient maintenance process and aligns the objectives of DSC & DSP. This review needs to be done by DSC and DSP together.

Fourth process step: Act
The last process step is the improvement of the PMS. Based on the findings from the review of the PMS improvement actions need to be taken. A possible improvement action is removing a Performance Indicator from the PMS, because the performance of the Performance Indicator cannot be improved anymore. Or adding a Performance Indicator to the PMS, because there are new problems identified in the maintenance process of the Zor-f plant which need to be measured.

9 Conclusions and discussion

The final chapter of this report presents the conclusions of this project. Besides, it discusses some recommendations for further research. Moreover, this chapter presents the limitations of this project.

9.1 Conclusions

This section answers the main research question of this project: *"What characteristics need to be managed in order to improve the maintenance process & equipment performance of the Zor-f plant, to stimulate DSC to carry out an effective & efficient maintenance process and to align the objectives of DSC & DSP?"* By answering this main research question the design objective of this project can be achieved: *"To design a performance measurement system that can be used to manage the maintenance process of the Zor-f plant and the Performance Based Contract between DSC & DSP in order to improve the maintenance process & equipment performance of the Zor-f plant, to stimulate DSC to carry out an effective & efficient maintenance process and to align the objectives of DSC & DSP".* The conclusions of this project can be divided into two main conclusions. Both conclusions are discussed below.

The literature review done in this project identifies seven characteristics that need to be measured in order to monitor the condition of a maintenance process. These are the characteristics: *equipment reliability, time to repair, maintenance costs, work identification, work planning, work scheduling* and *work execution*. Next, the analysis of the maintenance process of the Zor-f plant shows that the characteristics *equipment reliability, time to repair, maintenance costs, work planning* and *work execution* are important for the Zor-f plant. These characteristics are important for the Zor-f plant, due to fact that these characteristics are related to the maintenance objectives of the Zor-f plant, [redacted] and/or are highly dependent on each other at the Zor-f plant. Based on this and the formulated design requirements in this project the characteristics from literature are customized for the Zor-f plant. This results in seven characteristics that need to be measured in order to monitor the condition of the maintenance process of the Zor-f plant. These are the characteristics: *equipment reliability, time to repair, maintenance costs, labor estimation, work efficiency, first-time right work* and *schedule compliance.* Next, the evaluation shows that, managing the maintenance process of the Zor-f plant based on these characteristics, has the potential to improve the maintenance process and equipment performance of the Zor-f plant. So, the first conclusion is that the characteristics *equipment reliability, time to repair, maintenance costs, labor estimation, work efficiency, first-time right work* and *schedule compliance* need to be managed in order to improve the maintenance process and equipment performance of the Zor-f plant.

The literature review done in this project shows also that the characteristics *produced units* and/or *equipment reliability* in combination with *time to repair* need to be measured in order to define the incentive of a Performance Based Contract (PBC) in the manufacturing industry. Next, the analysis of the maintenance process and organization structure of the Zor-f plant shows that only the characteristic *time to repair* from literature is influenced by only DSC at the Zor-f plant. Based on this and the formulated design requirements in this project, can be concluded that only *time to repair* can be used in order to define the incentive of the PBC between DSC and DSP. Next, the evaluation shows that, managing the PBC between DSC and DSP based on this characteristic, has the potential to stimulate DSC to carry out an effective and efficient maintenance process. Besides, the evaluation shows that it aligns the objectives of DSC and DSP. So, the second conclusion is that the characteristic *time to repair* needs to be managed in order to stimulate DSC to carry out an effective & efficient maintenance process and to align the objectives of DSC & DSP.

All characteristics that need to be used for managing the maintenance process of the Zor-f plant and the PBC between DSC and DSP, can be measured by the Performance Indicators *Mean Time Between Failure, Mean Time To Repair, direct maintenance costs, labor estimation, man-power efficiency, rework* and *schedule compliance*. The seven Performance Indicators together create the new performance measurement system (PMS). This way a PMS is designed that can be used to manage the maintenance process of the Zor-f plant and the PBC between DSC and DSP in order to improve the maintenance process & equipment performance of the Zor-f plant, to stimulate DSC to carry out an effective & efficient maintenance process and to align the objectives of DSC and DSP. So, the new PMS designed in this project achieves the design objective of this project.

9.2 Recommendations

This section presents some recommendations for further research. The recommendations can be divided into recommendations for science and recommendations for DSC & DSP.

9.2.1 Recommendations for science

This project contributes to the science, because of two reasons. Firstly, because this project provides a literature framework that shows what needs to be measured in order to monitor a maintenance process and to define an incentive of a PBC in the manufacturing industry. This framework is unique, because it combines the two functions mentioned above. This framework can be used as starting point for designing a maintenance PMS for PBCs in the manufacturing industry. Next, this framework can be customized for a specific case in the manufacturing industry. Secondly, this project contributes to the science because it bridges the knowledge gap regarding what defines an incentive of a PBC, if a sole contractor delivers a maintenance service consisting of only the maintenance process, to a customer in the manufacturing industry. This way the scientific literature regarding PBCs in the manufacturing industry is elaborated. In order to approve that the findings of this project can be also found in other cases, the recommendation mentioned below needs to be performed.

- From a scientific perspective it is recommended to perform more case studies, in order to identify if using the new PMS for managing a maintenance process and a PBC has always the potential to improve a maintenance process & equipment performance of a plant, has always the potential to stimulate a contractor to carry out an effective & efficient maintenance process and aligns always the objectives of a contractor & customer. These case studies need to be done on plants where the situation is equal on the situation of the Zor-f plant. This means manufacturing plants where a customer has outsourced only the maintenance process to one contractor by a PBC.

9.2.2 Recommendations for DSC and DSP

This project is beneficial to DSP and DSC, because the new PMS designed in this project can replace the current PMS used by DSC and DSP. Hence, the intended objectives of the use of a PMS at the Zor-f plant can be achieved now. To benefit as much as possible from the new PMS the recommendations mentioned below need to be performed by DSP and DSP.

- For DSC and DSP it is recommended to start directly with the implementation of the new PMS at the Zor-f plant. This way the maintenance process and equipment performance of the Zor-f will be quickly improved. Besides, this way DSC will be quickly carry out a more effective and efficient maintenance process than currently. Also, the objectives of DSC and DSC will be directly aligned. In this project the focus is only on the Zor-f plant, but it is also recommended for DSP and DSC to implement the new PMS at the other plants of DSP in Delft where DSC carries out the maintenance process. This is possible, because the maintenance processes of the other plants are equal to the maintenance process of the Zor-f plant. As a result DSP and DSC can also benefit from the advantages of the new PMS at the other plants of DSP in Delft.

- In section 7.3 is mentioned that a weakness of defining the incentive by only the Performance Indicator *Mean Time To Repair* is that it creates looking for excuses. In order to prevent this, it is recommended for DSC and DSP to include a clear definition of the Performance Indicator *Mean Time To Repair* in the PBC. Two things need to be defined. First, needs to be defined what is included and excluded in the repair time. For example in Chapter 6 is mentioned that administrative and logistics delay time are excluded in the repair time. But what is administrative and logistics delay time? This needs to be defined. Besides, needs to be defined which maintenance activities are used to determine the *Mean Time To Repair*. For example only corrective maintenance activities with priority 0 and 1 related to critical equipment units or corrective maintenance activities with priority 0 to 4 related to all equipment units.

- It is recommended for DSC and DSP to do further research in order to define the incentive of the PBC between DSC and DSP by more than one Performance Indicator. Since, both DSC as DSP remark in section 7.3 that defining the incentive by one Performance Indicator has disadvantages. In this project the other aspects of the PBC, such as responsibilities, assignments, terms and conditions, etc. are considered as a fact. However, they should not be considered as a fact in further research, because these parts of the PBC can provide possible the solution for defining the incentive of the PBC between DSC and DSP by more than one Performance Indicator.

- At last, it is recommended for DSC and DSP to do further research in order to define the incentive of the PBC between DSC and DSP based on the performance related to corrective and preventive maintenance activities. Since, the new PMS defines the incentive of the PBC only based on the performance related to corrective maintenance activities. This is caused by the fact that *Time To Repair* is only relevant for corrective maintenance. By defining the incentive of the PBC based on the performance related to corrective and preventive maintenance activities, a completer overview of the performance of DSC is created for defining the incentive of the PBC.

9.3 Discussion

Next, it is important to present the limitations of this project. These limitations need to be considered during the implementation of the PMS at the Zor-f plant.

- In this project the characteristics measured by the new PMS are partially based on the problems in the maintenance process of the Zor-f plant. The problems in the maintenance process of the Zor-f plant are identified by interviews and observations, because quantitative data is currently not available for identifying the problems in the maintenance process of the Zor-f plant. Hence, it can be possible that problems are overlooked or that things are identified as problem, but are actually not a problem. Due to this, it can be possible that the new PMS does not measure the right characteristics in order to monitor the condition of the maintenance process of the Zor-f plant. As a result it can be possible that using the new PMS for managing maintenance process of the Zor-f plant does not improve the maintenance process and equipment performance of the Zor-f plant.

- In order to define the current state of the maintenance process and equipment performance of the Zor-f plant, in section 7.2.2 of this project, a lot of estimations are made. This is done, because currently not all required data is available to quantify the current state of all Performance Indicators. Hence, the defined current state of the maintenance process and equipment performance of the Zor-f plant can be substantially differ from the actual current state at the Zor-f plant. As a result of this, the evaluation can offer a strongly distorted picture of the potential improvement of the maintenance process and equipment performance of the Zor-f plant in section 7.2.4 of this report.

- Besides, the expected future state of the maintenance process and equipment performance, defined in section 7.2.3 of this project, is based on only estimations made by employees of the Zor-f plant. Therefore the estimates can be not objective, because the employees of the Zor-f plant can be overestimated the improvement that they can realize. As a result of this, the expected future state of the maintenance process and equipment performance can be estimated substantially better than the actual state will be in the future. Hence, in section 7.2.4 the evaluation can show more potential improvement of the maintenance process and equipment performance of the Zor-f plant than it will be in fact.

- In section 7.3 a SWOT-analysis is performed. Some of the strengths, weaknesses, opportunities and threats of the SWOT-analysis are contradictory. Since, a SWOT-analysis is a qualitative method it is not possible to define which side of a contradiction is stronger. As a result this, how the strengths, weaknesses, opportunities and threats have impact on the effectiveness and efficiency of the maintenance process is dependent on the interpretation of the researcher of this project, so is subjective. This means that the conclusion of this part of the evaluation can be different, when the evaluation is done by someone else than the researcher of this project.

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Appendix A - Interviews

Name	[redacted]
Function	[redacted]
1. Problems current KPI dashboard [13 September 2016] [redacted] - [redacted]	

Name	[redacted]
Function	[redacted]
1. Explanation current PMS [12 September 2016] [redacted] **2. Maintenance objectives DSC & DSP [31 Octobre 2016]** [redacted] **3. Calculation current Performance Indicator availability Zor-f plant [30 November 2016]** [redacted] ▪ [redacted]	

Name	[redacted]
Function	[redacted]

1. Background information PMS [1 September 2016]

[redacted]

2. Maintenance objectives [3 November 2016]

[redacted]

Name	[redacted]
Function	[redacted]

1. Design a PMS [16 January 2017]

[redacted]

- [redacted]

Name	[redacted]
Function	[redacted]

1. Maintenance objectives [28 October 2016]

[redacted]

Name	[redacted]
Function	[redacted]

1. Problems current PMS [7 October 2016]

[redacted]

2. Maintenance objectives [31 October 2016]

[redacted]

Name	[redacted]
Function	[redacted]

1. Explanation and problems current PMS [15 September 2016]

[redacted]

2. Maintenance objectives [1 November 2016]

[redacted]

3. Design PMS [20 December 2016]

[redacted]

- [redacted]

Appendix B - Maintenance objective tree Zor-f plant

Figure 26; Maintenance objective tree Zor-f plant

Appendix C - Swim lanes maintenance process Zor-f plant

Figure 27; Swim lane corrective WO with priority 0 or 1

Figure 28; Swim lane corrective WO with priority 2, 3 or 4 & preventive/predictive WO

Figure 29; Swim lane process step gatekeeping

Figure 30; Swim lane process step work planning & scheduling

Figure 31; Swim lane process step work execution & closing job

Appendix D - Evaluation based on requirements

This Appendix describes in more detail the evaluation of the current and new Performance Measurement System (PMS) based on requirements. This Appendix consists of four parts. The first part explains per requirement and constraint from section 5.2, if the requirement or constraint is met by the current PMS. Next, the second part of this Appendix does the same only then for the new PMS. The third part shows per Performance Indicator of the current PMS, if the Performance Indicator meets the requirements or constraints from section 5.3. The last part does the same only then for the Performance Indicators of the new PMS.

Part 1: Evaluation current PMS on PMS requirement and constraints from section 5.2

In this part of the Appendix is explained per functional requirement and per constraint from section 5.2, why the current PMS meets or does not meet the functional requirement/constraint. For the functional requirements and constraints from section 5.2, reference numbers are used in this Appendix. These reference numbers can be found in Table 13. In addition, reference numbers are used in this Appendix for the Performance Indicators of the current PMS. These numbers can be found in Table 14. In section 1.2 an explanation of the Performance Indicators of the current PMS is given.

Table 13; Reference number for requirements and constraints from section 5.2

Functional requirements:	
1.	The PMS should monitor at least one characteristic on strategical level of the maintenance department (Appendix A, [redacted]).
2.	The PMS should monitor at least one characteristic on tactical level of the maintenance department (Appendix A, [redacted]).
3.	The PMS should monitor at least one characteristic on operational level of the maintenance department (Appendix A, [redacted]).
4.	The PMS should monitor the maintenance process itself by more than half of the characteristics monitored/defined by the PMS (Stork technical services, 2016).
5.	The PMS should monitor at least two characteristics of the results of the maintenance process (Stork technical services, 2016).
6.	The PMS should monitor more than half of the identified problems in the maintenance process (Appendix A, [redacted]) (Stork technical services, 2016).
7.	The PMS should monitor all the process steps of the maintenance process that are highly dependent on each other (Appendix A, [redacted]).
8.	The PMS should monitor all important and relevant maintenance objectives (Stork technical services, 2016).
9.	The PMS should define the incentive of the PBC at least by one characteristic (Appendix A, [redacted]).
Constraints:	
1.	The PMS must define the incentive of the PBC by the outcome of the maintenance process (Hypko, Tilebein, & Gleich, 2010a).
2.	The PMS must define the incentive of the PBC by only characteristics that can be influenced by the contractor (Stork technical services, 2016).
3.	The PMS must monitor/define more characteristics than only the financial characteristics (Stork technical services, 2016).
4.	The PMS must monitor more characteristics than only the characteristics that define the incentive of the PBC (Behn & Kant, 1999).
5.	The PMS must not monitor/define more than ten characteristics (Stork technical services, 2016) (Appendix A, [redacted]).

Table 14; Reference numbers for Performance Indicators of current PMS

#	Performance Indicators of current PMS
1	Availability Zor-f plant
2	Top 5 performance killers provided with Root Cause Analysis
3	Actual costs vs budget
4	Replace asset base value
5	Top 5 cost drivers provided with Root Cause Analysis
6	Backlog work orders
7	Compliance tasks carried out on time
8	Hands on Tool Time measurement performed

Functional requirements:

1. Based on the information from section 6.3 can be concluded that this requirement is met, because five Performance Indictors of the PMS are related to the strategical level of the maintenance department of the Zor-f plant. These are the Performance Indicators 1,2,3,4 and 5.

2. Based on the information from section 6.3 can be concluded that this requirement is not met, because none of the Performance Indictors of the PMS is related to the tactical level of the maintenance department of the Zor-f plant.

3. Based on the information from section 6.3 can be concluded that this requirement is met, because three Performance Indictors of the PMS are related to the operational level of the maintenance department of the Zor-f plant. These are the Performance Indicators 6,7 and 8.

4. It can be concluded that this requirement is not met, because three of the eight Performance Indictors of the PMS are related to the maintenance process itself. These are the Performance Indicators 6,7 and 8.

5. It can be concluded that this requirement is met, because five Performance Indictors of the PMS are related to the results of maintenance process. These are the Performance Indicators 1,2,3,4 and 5.

6. Based on the information from section 4.7 can be concluded that this requirement is not met, because only one of the five identified problems in the maintenance process is monitored by the PMS. This is done by the Performance Indictor 7.

7. Based on the information from section 4.7 can be concluded that this requirement is not met, because not all the process steps that are high dependent on each other are monitored by the PMS. Only the execution process step is monitored by the PMS, by Performance Indicator number 6 to 8. The process step work planning is not monitored by the PMS.

8. Based on the information from section 4.3 can be concluded that this requirement is not met, because three of the four relevant maintenance objectivities of the Zor-f plant are monitored by the PMS. The maintenance objective related to the process step work planning is not monitored by the PMS.

9. It can be concluded that this requirement is met, because all the Performance Indicators of the PMS define together the incentive of the PBC.

Constraints:

1. It can be concluded that this constraint is not met, because all the Performance Indicators of the PMS define together the incentive of the PBC.

2. It can be concluded that this constraint is not met, because also DSP has influence on the Performance Indicators of the PMS which define the incentive of the PBC. DSP has influence on the Performance Indicators number 1 to 5.

3. It can be concluded that this constraint is met, because the PMS monitors the finance by three of the eight Performance Indicators of the PMS. These are the Performance Indicators 3,4 and 5.

4. It can be concluded that this constraint is not met, because all the Performance Indicators of the PMS define the incentive of the PBC, so there is no Performance Indictor that does not define the incentive of the PBC.

5. It can be concluded that this constraint is met, because the PMS consists of eight Performance Indicators.

Part 2: Evaluation new PMS on PMS requirements and constraints from section 5.2
Below is explained per functional requirement and per constraint from section 5.2, why the new PMS meets or does not meet the functional requirement/constraint. For the functional requirements and constraints from section 5.2, reference numbers are used in this Appendix. These reference numbers can be found in Table 13.

Functional requirements:

1. Based on Figure 21 can be concluded that this requirement is met, because the figure shows that three Performance Indictors of the PMS are related to the strategical level of the maintenance department of the Zor-f plant. These are the Performance Indicators *Mean Time Between Failure, Mean Time To Repair* and *direct maintenance costs.*

2. Based on Figure 21 can be concluded that this requirement is met, because the figure shows that one Performance Indictor of the PMS is related to the tactical level of the maintenance department of the Zor-f plant. This is the Performance Indicator *labor estimation.*

3. Based on Figure 21 can be concluded that this requirement is met, because the figure shows that three Performance Indictors of the PMS are related to the operational level of the maintenance department of the Zor-f plant. These are the Performance Indicators m*an-power efficiency, rework* and *schedule compliance.*

4. Based on Figure 22 can be concluded that this requirement is met, because the figure shows that four of the seven Performance Indicator of the PMS are related to the maintenance process itself. These are the Performance Indicators *labor estimation, man-power efficiency, rework* and *schedule compliance.*

5. Based on Figure 22 can be concluded that this requirement is met, because the figure shows that three Performance Indicators of the PMS are related to the results of maintenance process. These are the Performance Indicators *Mean Time Between Failure, Mean Time To Repair* and *direct maintenance costs.*

6. Based on the information from section 4.7 can be concluded that this requirement is met, because four of the five identified problems in the maintenance process are monitored by the PMS. This is

more than half of the problems. These is done by the Performance Indictors *labor estimation, man-power efficiency, rework* and *schedule compliance.*

7. Based on the information from section 4.7 can be concluded that this requirement is met, because all the process steps that are high dependent on each other are monitored by the PMS. These is done by the Performance Indictors *labor estimation, man-power efficiency, rework* and *schedule compliance,* related to the process steps work planning and work execution.

8. Based on the information from section 4.3 can be concluded that this requirement is met, because four of the four relevant maintenance objectivities of the Zor-f plant are monitored by the PMS. These is done by all the Performance Indictors of the PMS.

9. Based on Figure 22 can be concluded that this requirement is met, because the figure shows that the PMS defines the incentive of the PBC by the Performance Indicator *Mean Time To Repair.*

Constraints:

1. Based on the information from section 6.1 and Figure 22 can be concluded that this constraint is met, the Performance Indicator that defines the incentive of the Performance Bases Contract, *Mean Time To repair,* is related to the outcome of the maintenance process.

2. Based on the information from section 6.1 and Figure 22 can be concluded that this constraint is met, the Performance Indicator that defines the incentive of the Performance Bases Contract, *Mean Time To repair,* is only influenced by DSC.

3. Based on Figure 22 can be concluded that this constraint is met, because the PMS consists of one Performance Indicator, *direct maintenance costs,* that is related to finance and consists of six Performance Indicators that are not related to finance.

4. Based on Figure 22 can be concluded that this constraint is met, because the PMS consists of one Performance Indicator, *Mean Time To Repair,* that is related to the incentive of the PBC and consists of six Performance Indicators that are not related to the incentive of the PBC.

5. Based on Figure 22 can be concluded that this constraint is met, because the PMS consists of seven Performance Indicator.

Part 3: Evaluation current PMS on PI requirements and constraints from section 5.3

Table 15 shows for each Performance Indicator of the current PMS if the Performance Indicator meets the functional requirement and the constraints from section 5.3.

Table 15; Evaluation current PMS on PI requirement and constraints

		Performance Indicator								
	Functional requirement:	1 Availability Zor-f plant	2 Top 5 performance killers provided with RCA	3 Actual costs versus budget	4 Replacement Asset Base (RAB) value	5 Top 5 cost drivers provided with RCA	6 Backlog work orders	7 Compliance tasks carried out on time	8 Hand on Tool Time measurement performed	**% PI of PMS meets requirement or constraint**
1	A Performance Indicator should measure a characteristic needs to be monitored/defined by the PMS.	✓	✓	✓	✓	✓	✓	✓	✓	**100**
	Constraints:									
1	A Performance Indicator must be understood without explanation (Parida & Kumar, 2006).	✓		✓	✓		✓	✓	✓	**75**
2	A Performance Indicator should measure one characteristic needs to be monitored/defined by the PMS (Parida & Kumar, 2006).	✓	✓	✓	✓	✓	✓	✓	✓	**100**
3	A Performance Indicator must be calculated by only quantitative data (Parida & Kumar, 2006).	✓		✓	✓		✓	✓		**63**
4	A Performance Indicator should show different values over a long period of time (Stork technical services, 2016).	✓		✓	✓		✓			**50**
5	A Performance Indicator should not measure an activity (Appendix A, [redacted].	✓		✓	✓		✓			**50**

Part 4: Evaluation new PMS on PI requirements and constraints from section 5.3

Table 16 shows for each Performance Indicator of the new PMS if the Performance Indicator meets the functional requirement and the constraints from section 5.3.

Table 16; Evaluation new PMS on PI requirement and constraints

		Performance Indicator							
	Functional requirement:	1 Mean Time Between Failure	2 Mean Time To Repair	3 Direct maintenance costs	4 Labor estimation	5 Man-power efficiency	6 Rework	7 Schedule compliance	**% PI of PMS meets requirement or constraint**
1	A Performance Indicator should measure a characteristic needs to be monitored/defined by the PMS.	✓	✓	✓	✓	✓	✓	✓	**100**
	Constraints:								
1	A Performance Indicator must be understood without explanation (Parida & Kumar, 2006).	✓	✓	✓	✓	✓	✓	✓	**100**
2	A Performance Indicator should measure one characteristic needs to be monitored/defined by the PMS (Parida & Kumar, 2006).	✓	✓	✓	✓	✓	✓	✓	**100**
3	A Performance Indicator must be calculated by only quantitative data (Parida & Kumar, 2006).	✓	✓	✓	✓	✓	✓	✓	**100**
4	A Performance Indicator should show different values over a long period of time (Stork technical services, 2016).	-	-	-	-	-	-	-	**-**
5	A Performance Indicator should not measure an activity (Appendix A, [redacted]).	✓	✓	✓	✓	✓	✓	✓	**100**

Appendix E - Scenarios evaluation[5]

Table 17; Scenario 1: preventive work orders G280 in 2016

[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
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Table 18; Scenario 2: corrective work orders G280 in 2016

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[5] Highlighted work orders in this Appendix have priority 0 or 1 (for the meaning of priority 0 and 1 see section 4.5)

Table 19; Scenario 3: preventive work orders G500 in 2016

[redacted]	[redacted]
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Table 20; Scenario 4: corrective work orders G500 in 2016

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Table 21; preventive work orders V260 in 2016

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[redacted]	[redacted]
[redacted]	[redacted]
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Table 22; Scenario 6; corrective work orders V260 in 2016

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Table 23; Scenario 7: preventive work orders V020 in 2016

[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
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Table 24; Scenario 8: corrective work orders V020 in 2016

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Appendix F - Expected future state

Table 25; Expected future state maintenance process and equipment performance defined by the maintenance supervisor of the Zor-f plant[6]

[redacted]

Table 26; Expected future state maintenance process and equipment performance defined by the maintenance manager of the Zor-f plant[7]

[redacted]

Table 27; Expected future state maintenance process and equipment performance defined by the contract manager from DSC[8]

[redacted]

[6] Maintenance supervisor Zor-f plant is [redacted]
[7] Maintenance manager Zor-f plant is [redacted]
[8] Contract manager from DSC is Niels [redacted]