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Master thesis
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A practical approach to maintenance performance measurement

Shifting the focus from the alignment with strategic objectives

to

the managerial possibilities to improve maintenance effectiveness and efficiency

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Zutphen, February, 2015

Acknowledgements

The time I spent on my thesis has been great. Experiencing the maturation of an idea of my own has been interesting. After all, it is satisfying to finish a root cause analysis, develop an alternative approach and apply the approach to FMS. All carried out to show the comprehensiveness and quality of an idea. It is definitely more satisfying than implementing a limited approach prescribed by literature. It takes a little more time, but then you have some.

With rowing you compete with people who have the same objectives. In research you compete with your own and with other people’s approaches. The only request of Fred, the commissioner of the project, was a practical approach as there were no pressing subjects (and data) to deal with. The competitors have failed reaching the goal of developing a practical approach so I took the lead. I knew that the finish would be my graduation, but I was not aware of the efforts that would be required to win the challenge. It has not been a perfect race.

After trying to work with, bend and shape the current approaches, I had to conclude that the standard approach was cut off the basics. On a side note, back to basics seems to suit me. It’s what happened when I went back to my mom in Zutphen after I left 7.5 years ago, it’s the motto of the board I chaired a few years ago, it’s what I like in philosophy, and it’s what was required in the field of maintenance performance measurement (MPM). The competitors were strategy minded. Although I also like strategic issues, optimising dealing with deterioration primarily strategically seems to miss the boat. At several moments in the process I was afraid I missed something in my comprehensive approach.

It’s hard to quit the process, because it’s not perfect. Nevertheless, I’m happy to have revealed the basics of MPM. Moreover it has been nice to develop a practical approach that points to solutions. The quality of literature’s MPM has been at such a level that MPIs pointing to a solution is considered as an “ultimate performance indicator”. The decision to reveal that something is not perfect does not need an academic approach, I would say. The recommendation to start a root cause analysis does not need it either. So, I’m happy to present my MPM approach with ultimate performance indicators.

I think Matthieu is also happy that I’m finished. Matthieu, thanks for your time and efforts to support me. I hope I did not bother you too much with my alternative approach to MPM and that you can appreciate the work. Rob, thanks for your support, I appreciate all the help and the Skype session when you were at the other side of the world.

Fred and Jacques, thanks for the time in Leidschendam and the efforts to support me. I hope you can measure the maintenance performance in a couple of months. Good luck with retrieving recognition of the maintenance organisation. The MPM approach is ready to support you in a practical way.

Finally, I would like to thank my mom and Paul. It’s again time to celebrate the day.

Dirk-Jan Fokkens

Management summary

Fugro supports clients by acquiring, processing and interpreting geological data. Fugro's geological activities include the research of the seabed and below. Over fifty specialised vessels are currently involved with offshore projects. Fugro Marine Services (FMS), the in-house vessel managing company since 2005, strives to become the preferred supplier of vessel management solutions for Fugro Operating Companies (OpCos). Currently FMS is not able to measure maintenance performance. As it is closely related to providing available vessels, FMS is facing difficulties quantifying vessel management quality.

Maintenance performance measurement (MPM) literature is struggling with the development of practical approaches to MPM. Improving maintenance is about reducing costs of deterioration. Costs of deterioration include costs of maintenance and costs of unavailability of equipment. Current MPM literature's primary objective is to align maintenance performance indicators with strategic objectives. This alignment does not establish the link to possibilities to deal with the effects of deterioration. Literature's approach is limited to starting root cause analyses when strategic objectives are not achieved. This research has developed and applied an alternative approach:

The objective of the research is to develop a MPM approach that indicates and prioritises FMS' maintenance improvements in order to maximise the profits of the OpCo

Rooting the MPM approach in the managerial possibilities to influence maintenance has resulted in a practical approach to MPM. The research objective is achieved. The MPM approach is applied to FMS. The deliverables of the research are:

1. A MPM approach supporting the evaluation of all managerial maintenance decisions available to minimise the costs of deterioration.
2. A comprehensive managerial decision area framework that is generally applicable for all installed bases, including vessels.
3. A set of MPM performance indicators directly linked to managerial decisions to improve job supporting resources.
4. A FMS specified selection of performance indicators.
5. A FMS specified overview of required data.
6. A decision support tool (DST) to support maintenance evaluation.
7. A selection of improvement projects based on the current policy level and costs.

MPM supports maintenance evaluation. Insights in optimal maintenance decision making is required to set up useful maintenance performance indicators (MPIs). The research' MPM approach is shown in Figure 1:

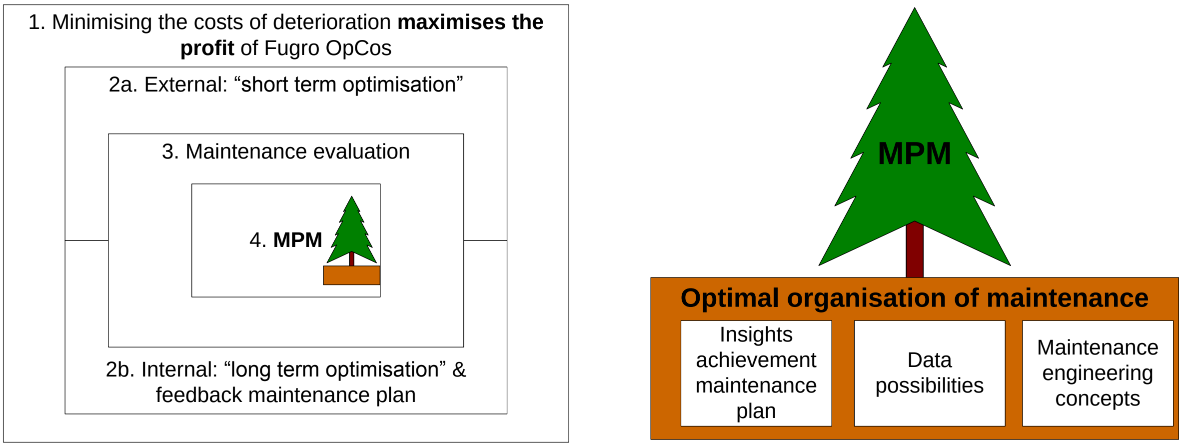

Figure 1 Overview research' MPM approach

A comprehensive framework of managerial possibilities to influence maintenance performance is constructed. Optimal organisation of maintenance minimises the *expected* costs of deterioration. The reliability of cost expectations depends on data. Transparency of direct costs and risks supports deciding to exploit a managerial possibility to influence maintenance. The transparent overview supports of maintenance evaluation:

1. Show quality of maintenance by showing optimality of decision making

2. Support the short term alignment of the maintenance plan with budgetary restrictions

3. *Prioritise maintenance improvements* (the comprehensive approach has identified the managerial possibilities to improve maintenance)

4. Generate feedback on the execution of the maintenance plan

The research has developed the MPIs that reveal performance gaps and identify the costs involved with a maintenance engineering concept. These maintenance improvements are prioritised by the costs and delays involved.

The MPM approach is applied to FMS. The general MPIs are aligned with FMS specific characteristics of maintenance. E.g. the vessel statuses, limited repair and delivery possibilities offshore, and weather conditions. The resulting MPIs and prescribed data are proven to fit the purpose of performance measurement by:

1. The evaluation of identified literature's basics of performance measurement for a comprehensive evaluation of the effectiveness and efficiency of maintenance.
2. The discussion of the usability of the MPM results (MPIs and data) visualised by the DST with a dummy dataset with the maintenance experts of FMS.

MPM's required data entries are not available at FMS. Consequently maintenance improvements on the job level are not provided by the research. It is recommended that the dry docking preparations and the crew selection procedures are evaluated, because of the order of magnitude of costs and current lacking systematic approaches.

FMS should convert the information system 'Star' to enable maintenance evaluation. When data is gathered, the maintenance evaluation procedures needs to be developed to support the 4 functions mentioned above. The recommendations are:

1. Currently, 51 of the 70 required entries are gathered. The remaining 19 entries are essential for the performance overview. These need to be created in the system. The types of entries are similar to existing entries. It is not expected to be an issue.
2. The input of 'Star' needs to be converted to the input of the DST, which is an Excel spreadsheet. 'Star' is capable of reporting to Excel spreadsheets. This needs to be programmed.
3. All 70 data entries are required. To minimise the efforts of MPM, 'Star' output should match the DST input. The 'Star' developers, the DST programmer and the end-user need to collaborate to ensure the MPM results are easily calculated.

Future research should focus on:

1. Evaluation of the general applicability of the MPM approach to other industries.
2. Estimating the value of maintenance: "the costs that would have occurred otherwise".
3. Downtime risk estimations to determine the risks given a certain strategic budget.
4. Development of a practical tool to support (strategic) design decisions with maintenance performance expectations

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List of abbreviations and definitions

Commercial availability/ downtime: time when the vessel is able / a breakdown prevents conducting a commercial project

Corrective maintenance: necessary replacement or repair to solve the broken part.

Critical components: the components that are required to work to operate the system.

Decision support tool (DST): a tool to support managerial decision making

Dry docking maintenance (DDM): a time of maintenance that the vessel is laid up in a dry dock.

Effective maintenance: the degree of minimal effects of deterioration on the availability of the vessel for commercial projects by carrying out maintenance. The optimum depends on the natural failure behaviour and maintainability of the equipment.

Efficient maintenance: the degree of minimal usage of resources to carry out the maintenance plan. The optimum depends on the optimal organisation of resources (which contains varying optimisation problems).

Fugro Marine Services (FMS): internal service provider vessel management for Fugro

Fugro Standard Survey Vessel (FSSV): a type of survey vessel of which four are sailing.

Job supporting resource: the job supporting resources are trained personnel, spare parts and repair materials, facilities, technical documentation, tools, support and test equipment, and time.

M&RE department: Maintenance and Reliability Engineering department

Maintenance: the activity of dealing with the effects of deterioration by executing maintenance jobs on equipment

Maintenance engineering (ME): the field of engineering concepts to optimise the organisation of maintenance.

Maintenance engineering concept: an approach to solve a maintenance optimisation problem. E.g. cost minimisation and resource allocation problems.

Maintenance evaluation: the activity of assessing maintenance performance with MPM results with the goal to initiate projects to improve maintenance performance

Maintenance function: the maintenance function of a company involves all activities of maintenance, including related purchasing activities and inventory management.

Maintenance opportunity (MO): a maintenance opportunity is a moment of time the vessel is out of operation due to other reasons than maintenance. Performing the job would not cause additional downtime or delays.

Maintenance performance: maintenance performance is the effectiveness and efficiency of maintenance

Maintenance performance indicator (MPI): an entity that points to a solution to improve maintenance effectiveness or efficiency

Maintenance performance measurement (MPM): retrieving maintenance performance indicators that support the evaluation of maintenance

Maintenance performance measurement approach: the definition of maintenance performance and functionality of corresponding maintenance performance indicators

Maintenance performance measurement results: set of calculated maintenance performance indicators supporting maintenance evaluation

Maintenance plan: resulting maintenance jobs from the selected maintenance strategy. The maintenance plan prescribes per piece of equipment what and in which period the preventive maintenance jobs have to be carried out and what preparations should be taken to deal with failures.

Maintenance policy: per job supporting resource, refers to the way the job supporting resource is organised

Maintenance strategy: the selected approach of dealing with equipment's deterioration (e.g. failure based, time based, usage based, condition based)

Managerial decision (MD): the decision to initiate an improvement project to solve an optimisation problem

Managerial evaluation: the managerial evaluation assesses whether the maintenance plan is carried out according to the plan.

Operating Company (OpCo): companies conducting commercial projects under the name of Fugro

Optimisation problem: optimisation problems include cost minimisations and delays of the preventive maintenance plan[1]

Organisation of maintenance: the organisation of maintenance is about strategic, tactical and operational managerial decision making.

Original Equipment Manufacturer (OEM): supplier producing its equipment

Performance indicators: the core information to support managerial decision making

Preventive maintenance*:* maintenance is conducted to improve the condition of the component to extend the time between failures. It can be calendar time based, use based, load based or condition based maintenance.

Star Information Systems ('Star'): Star Information System is the software vendor of 'Star', which is the information system that FMS uses to manage its fleet.

Technical documentation (TD): a maintenance job supporting resource. At FMS the TD is assumed to be included with the delivery of purchased equipment.

Technical evaluation: The technical evaluation assesses whether the maintenance plan minimises the effects of deterioration. Improving the maintenance plan requires a lot of data.

Vessel status*:* The minimal status of a vessel to conduct a maintenance job can be "In operation", "Sailing", "For anchorage", "Alongside" and "Dry dock".

[1] Durations of critical repairs are accounted for by downtime costs; the increased risk on failures of delays of preventive maintenance jobs is not quantified, thus cannot be solved as a cost minimisation.

1 Introduction research

Available equipment is required to generate revenues. Maintenance performance measurement (MPM) is required to evaluate effectiveness and efficiency of maintenance: effective maintenance minimises the effects of equipment's deterioration on the performance of equipment; efficient maintenance minimises costs to carry out required maintenance. The vessel management company Fugro Marine Services (FMS) lacks an approach to evaluate maintenance performance, including an overview of the required performance measures. The result is a struggle to prove vessel management quality. Challenging, literature also lacks a practical approach to MPM (Simões et al., 2011). This thesis provides a practical approach to measure and improve FMS' maintenance performance.

This research is commissioned by the Maintenance & Reliability Engineering (M&RE) department, located at the headquarters of Fugro Marine Services (FMS) in Leidschendam. Section 1.1 introduces Fugro and FMS. Section 1.2 discusses the research plan.

1.1 Fugro's maritime business

This section starts with a global overview of Fugro in Section 1.1.1. Section 1.1.2 discusses the role of FMS.

1.1.1 Fugro overview

In 1962 Fugro was founded. In fifty years Fugro has become a world leading geological specialist. The specialism concerns exploiting natural resources and solving infrastructural challenges by acquiring, processing and interpreting geological data. The organisation is organised into different Operating Companies (OpCos) with over 250 offices in over 60 countries. The services provided by the OpCos are organised in four divisions: Geotechnical, Survey, Subsea Services and Geoscience (Fugro, 2013, p11-12). Appendix I provides an chart of Fugro's organisation.

All divisions are involved with research of the seabed and below. Therefore different OpCos own one or multiple vessels. Fugro´s commercial projects require non-conventional functions of the vessels. Therefore, the vessels are specially built for Fugro's purposes. Revenues are missed when a vessel is unavailable.

1.1.2 Fugro Marine Services

Fugro started the non-profit in-house vessel management company FMS in 2005. FMS takes care of the marine related issues, including maintenance. FMS does not own a vessel and requires budgets to operate and maintain the vessels every year. FMS' vision is to become the preferred supplier of fleet management solutions for Fugro's OpCos before the year 2020 by offering high quality services. It is not mandatory for the OpCos to select FMS for providing vessel management services. So far, the fleet that FMS manages and operates on behalf of OpCos has grown to 17 vessels.

The OpCos strive to operate offshore 24/7 when weather permits. A reason to start an in-house vessel managing company has been the opportunistic behaviour of external vessel managing companies. Bottom line: although the low maintenance costs on the short term are tempting, opportunistic behaviour is not expected to maximise availability on the approximated vessel's lifespan of 25 years. However, in hard economic times it is increasingly important for FMS to prove optimal use of money, as every euro saved increases the OpCo's profit (Fugro, 2014b).

FMS lacks the insights to prove the maintenance value of the OpCos' money, which is not improving the competitiveness of FMS. To put FMS' struggle into perspective, Chapter 3 argues that current Maintenance Performance Measurement literature is struggling with practical solutions for optimising maintenance and corresponding maintenance value.

1.2 Research design

The research design is constructed according to the methodology of Verschuren & Doorewaard (2007, P16-17, P160). The methodology starts with an overview of the current challenges faced in the project framework, shown in Section 1.2.1. The contribution of the research to the project framework is formulated in Section 1.2.2. Section 1.2.3 shows the required steps to achieve the objective. Section 1.2.4 shows the research questions and the thesis outline. The scope is discussed in Section 1.2.5.

1.2.1 Project framework

FMS provides vessel management services to Fugro OpCos. Firstly, the services include the legal and operational requirements to operate in commercial projects. Secondly, FMS is in charge of maintenance to control the condition of the vessel. FMS activities related to vessels are directly financed by the OpCo. Therefore, vessels' budgets need OpCo's approval every year. Reducing the costs of the OpCo, directly increases its profits.

The maintenance objectives at the budgetary meetings of the OpCo and FMS are not necessarily aligned. The OpCo requires achieving yearly profitability goals, and might aim to reduce maintenance costs. As FMS strives to provide high quality vessel management solutions, FMS has set up the maintenance plan to optimise vessel availability over the vessel lifespan. The plan is based on suppliers' recommendations that tend to prescribe much maintenance. As it is not mandatory for the OpCos to select FMS for vessel management services, the OpCo can swap vessel management when they are not satisfied.

There might be other reasons to change vessel management than high maintenance costs. Those reasons are outside the scope of the research. To solve the dispute regarding maintenance, the value of maintenance is of interest. Precise estimations of the vessel performance require modelling of failure behaviour under different maintenance settings. Modelling requires a lot of data, which is currently not available.

Regardless the quality of deterioration modelling, short term financial goals can predominate. Consequently, an approach supporting the achievement of short term goals is required. When the cost control uses the latest data available to minimise risks on downtime, FMS adds value.

1.2.2 The research objective

The project framework describes a need for insights in the possibilities to organise maintenance given budgetary constraints. The budget might require a reduction of direct costs of planned (preventive) maintenance, but this increases the risk on unplanned (corrective) maintenance. Maintenance costs include missed revenues. The challenge is to minimise the total costs of maintenance. Minimising the costs of maintenance over the lifespan of a vessel, maximises the profits of the OpCo. The evaluation of maintenance reveals whether performance is optimal. The optimal decision depends on the available information (Dekker, 1996, P235-236). Maintenance performance measurement (MPM) supports the evaluation of maintenance by using operational data.

The objective of the research is to develop a MPM approach that indicates and prioritises FMS' maintenance improvements in order to maximise the profits of the OpCo

The MPM approach requires an overview of decisions to influence maintenance costs. Decisions are prioritised by the measured costs of the specific period. The initiation of maintenance improvement projects requires an evaluation of the MPM results. The decision to actually initiate maintenance improvements requires other sources of information. Decision making requires experience, level of optimality of current decision and market possibilities.

As literature lacks a practical approach to maintenance performance measurement, we have developed our own approach that is not only limited to measuring performance, but also able to prioritise improvement projects. The general deliverables of the research are:

1. A MPM approach suitable to periodically optimise effectiveness and efficiency of maintenance
2. A comprehensive managerial decision area framework that is generally applicable for all installed bases, including vessels
3. A set of maintenance performance indicators directly linked to managerial decisions

FMS' deliverables of the research are:

4. Specific set of performance indicators
5. Specific set of required data
6. A decision support tool (DST) to support FMS' maintenance performance evaluation
7. Highest priority maintenance improvement projects

1.2.3 Research model

The research model is shown in Figure 2.

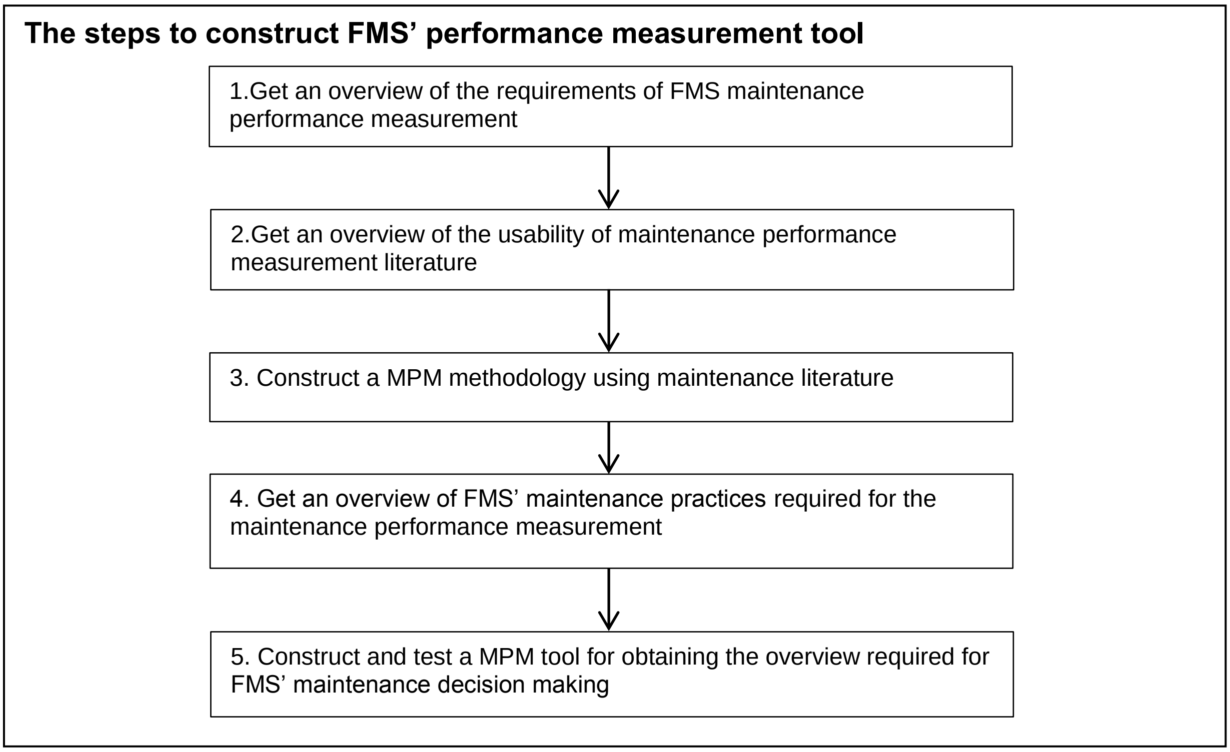

Figure 2 Research model

The project framework has introduced the relation of FMS and the OpCo. The organisation of maintenance is related to the vessel availability, which can add value when properly organised and measured. First step is to get an overview of the possibilities of MPM.

Secondly, the functionality of current MPM literature is discussed. Literature lacks a practical approach to measure maintenance performance (Simões et al., 2011). Moreover Muchiri et al. (2011, P302) have identified that the exact way of improving maintenance by MPM requires further research. Understanding the cause of the lacking practicality, prevents us from making a similar mistake.

The third step is the construction of our MPM approach. Maintenance engineering literature is primarily concerning the design of maintenance from scratch. The primary design decisions are possible solutions to improve maintenance performance. Maintenance engineering literature is used to set up a comprehensive overview of managerial maintenance decisions, which form the basis of the developed MPM approach.

The MPM approach prescribes what kind of information is required to set up the MPM tool. The fourth step identifies FMS' required maintenance details.

The fifth step is the construction and test of the decision support tool to prove that the data fits the calculations required for the MPM that enables the maintenance evaluation.

1.2.4 **Research questions**

Five main questions are formulated to accomplish the research objective. The first step is to get an overview of FMS required functionality of maintenance evaluation, which uses MPM results. Currently, there is no systematic approach of assessing maintenance performance.

- *Question 1) What is the potential usefulness of FMS' maintenance performance measurement?*

Chapter 2 shows the role of MPM to the primary objective of FMS: providing OpCos with high quality vessel management services. Based on interviews and the baseline study, shown in Appendix II, the potential role of maintenance performance measurement is discussed.

MPM literature lacks a practical approach to MPM (Simões et al., 2011). Literature is evaluated to reveal the difficulties with improving maintenance:

- *Question 2) Why is maintenance performance measurement literature not able to come up with a practical approach?*

Chapter 3 shows that the common starting point of MPM is to measure the achievement of strategic objectives. The usefulness to actually guide maintenance improvements is discussed. Ultimate performance indicators point towards solutions to improve maintenance (Wireman, 2005, Pvii).

The objective is to develop a MPM approach to prioritise maintenance improvements. The maintenance decisions form the basis of the MPM approach:

- *Question 3) What is a comprehensive set of managerial maintenance decisions founded on maintenance engineering literature?*

In Chapter 4 maintenance engineering literature is used to construct a comprehensive set of possible managerial decisions to influence maintenance. The set is based on the objective of maintenance evaluation, the link to maintainability design, maintenance strategy planning, the execution of the maintenance plan and the job supporting resources involved. Further, the basis is summarised in ten points of maintenance evaluation. These points are used to validate the developed MPM tool in Chapter 6. Finally, the comprehensive set of managerial decision areas is derived.

The data needs to be aligned with the characteristics of FMS' vessel maintenance:

- *Question 4) What data is required to set up the information to support FMS' managerial decision making?*

In Chapter 5 the information and corresponding data are identified to enable the maintenance evaluation. This requires an analysis per FMS' job supporting resource. The result of the chapter is an overview of data per job and per job supporting resource. At FMS the infrastructure and general data gather practises are in place. With some adjustments of the information system 'Star', the data gathering can be started.

To show the functionality of the MPM approach and the derived data, a MPM tool needs to be constructed and tested:

- *Question 5) How to display, interpreted and prioritise the performance indicators to support maintenance improvements?*

Chapter 6 shows and discusses the performance indicators per managerial decision area. The MPM tool is tested with a dummy dataset. The resulting tool needs to be validated and verified. As the total values involved with certain job supporting resources are identified at the “Baseline study”, an initial prioritisation of improvement projects turns out to be possible.

1.2.5 **Scope**

In this research are of interest all managerial maintenance possibilities to control and improve maintenance given the design of the operational installed base. Chapter 2 discusses the usability of controlling maintenance, which is closely related to the required MPM to evaluate maintenance.

More general, improvements are possible when the maintenance organisation is not optimal. Optimal maintenance is maximal effective and efficient (Neely et al., 1995, P80-81). Optimal maintenance organisation minimises the expected total costs, given the information available (Dekker, 1996, P235-236). Maintenance evaluation assesses the effectiveness and efficiency of maintenance. MPM supports the maintenance evaluation. Improvements not related to effectively or efficiently dealing with deterioration are outside the scope of this research.

The data overview to enable the maintenance evaluation is constructed and tested with a DST. This is based on a dummy dataset, as the required data is not available at FMS. The consequence is that providing feedback on FMS maintenance performance is limited to recommendations based on the magnitude of costs.

Maintenance improvement projects initialise solving cost minimisation problems, which are a type of optimisation problems. The effect of maintenance on the availability is integrated in the cost minimisation problem by estimating downtime costs. Reliability of estimations depends on available data. Solving the cost minimisation problems is outside the scope of this research.

When an improvement is not related to a maintenance job supporting resource, it is not a maintenance improvement and outside the scope of this research. Section 4.5 identifies the 6 job supporting resources.

2 MPM at Fugro Marine Services

FMS' maintenance performance is related to costs and vessel availability. These directly influence the profit of the OpCo, either by costs or missed revenues. *At FMS there is no systematic approach to evaluate maintenance*. This chapter elaborates on the functionality of maintenance performance measurement (MPM) for FMS' maintenance evaluation.

FMS faces a direct need to prove vessel management quality to the OpCo, as will be shown in Section 2.1. Section 2.2 provides an overview of functionality of controlling maintenance performance for external and internal purposes. Section 2.3 concludes the chapter with an overview of MPM and the relation to the OpCo's profits.

2.1 Fugro OpCo and the selection of a vessel management company

Fugro OpCos' core business is gathering, analysing and interpreting geological data. As the seabed is subject of research, vessels are required. Management of these vessels is outsourced. The quality of external vessel managing companies has been unsatisfying, so FMS has been started in 2005. Back then the primary concern was not to minimise costs, but to provide high quality vessel management services under the Fugro flag. Currently, revenues are not certain anymore. This increases the need of cost control (Fugro, 2014b). Figure 3 shows the vessel management decision making process.

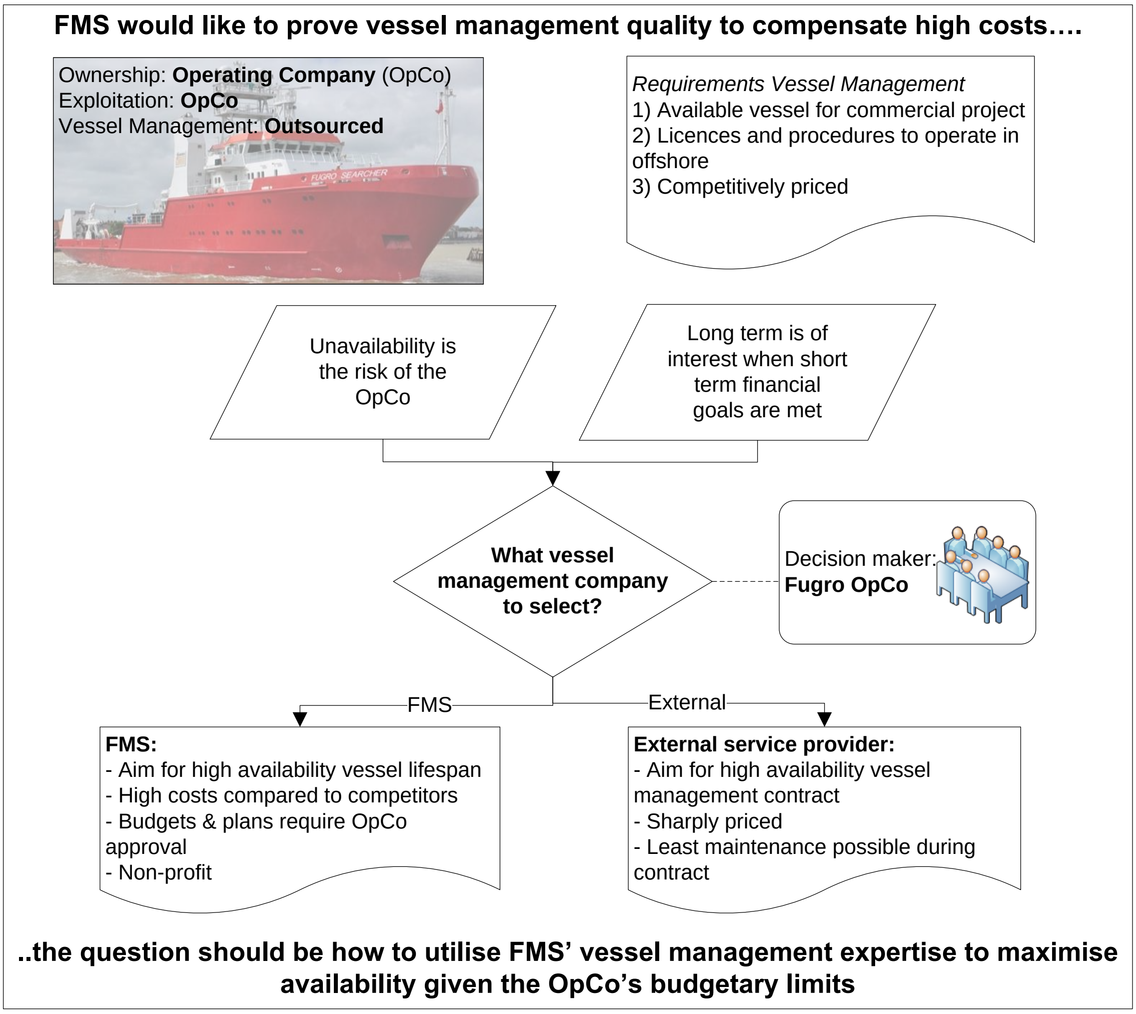

Figure 3 OpCo and vessel management selection

FMS' client is a Fugro OpCo. The OpCo requires a service provider that offers high quality vessel management services that fit the budget. FMS aims to maximise performance over the vessel lifespan of 25 years. The OpCo's short term budget requirement and FMS' aim to maximise performance on the long term require the same insights in maintenance. FMS requires controlling the possibilities to influence the costs of deterioration. The costs include the costs to deal with deterioration (maintenance) and the costs of the effects of deterioration. Costs of the effects of deterioration are the costs of unavailability.

FMS does not generate revenues, nor is financially responsible for the costs of deterioration. Therefore FMS' long term goal is less important than the OpCo's short term. When FMS is unable to satisfy OpCo's short term goals, FMS risks the vessel management assignment. Maintenance expertise contributes to the quality of vessel management. The expertise is related to the quality of decision making to minimise costs of deterioration. The best decision depends on the information available (Dekker, 1996, P235-236). The best FMS can do is exploit their vessel management expertise to support the OpCo's decision making. Currently they do not have the capability to generate and use relevant MPM results.

The chapter's introduction mentioned that FMS lacks a systematic approach of maintenance evaluation. This is not unique. Chapter 3 will elaborate on the lacking practicality in MPM literature. When industry would have had a practical approach to MPM, this would have been noticed. *Therefore controlling maintenance decision making by using latest MPM results*, *provides a unique position in the market*. The link between MPM, maintenance evaluation and profits is shown in Section 2.3. The requirement is to implement a practical approach.

2.2 Functionality of controlling maintenance

The quality of FMS' organisation depends on the quality of decision making. A comprehensive set of managerial decisions to influence maintenance forms the controls to manage maintenance performance. Chapter 4 provides a comprehensive set of managerial decision areas. The functionality of controlling maintenance is discussed in this section.

The functionality of controlling maintenance for external purposes is discussed in Section 2.2.1. The functionality for internal purposes is discussed in Section 2.2.2.

2.2.1 External functionality of controlling maintenance

Section 2.1 showed that in FMS' case there is an external need of measuring the quality of maintenance. The budget holding OpCo requires insights in the return on maintenance investment. Maintenance organisation is about minimising the costs of deterioration. Tear and wear and corresponding deterioration of equipment is given. The return of maintenance is available equipment and reduced risks of downtime.

Vessel management is about providing available vessels. FMS expertise of maintenance is a key factor to provide vessel management quality. *When one can show the client that all relevant maintenance decisions are optimised with respect to current (data) restrictions, it is shown that current maintenance is organised as good as possible.* Information is increasing when operational data is gathered. A systematic approach of evaluating performance is required to ensure the best decisions. A comprehensive overview of managerial decisions is required to set up proper maintenance performance indicators.

Data to predict costs of deterioration is limited. Moreover, predictions will never be fully certain. The maintenance plan is supposed to minimise the costs of deterioration during the lifespan of a vessel. When the budgetary possibilities are less than required to carry out the maintenance plan, FMS should do the following:

1. Adjust the maintenance plan with minimal risk on downtime given the OpCo's maintenance budget
2. Approximate the increased risk on downtime and corresponding costs of the maintenance plan that fits the sub-optimal budget

At FMS, the client is the budget holder. It is the client's decision to either accept the increased risk on downtime, or increase the budget for maintenance. *Both options are currently not supported by an overview of the distribution of maintenance costs, related decisions and latest data.* The current discussion remains intuitive and based on general experiences.

2.2.2 Internal functionality of controlling maintenance

The evaluation of maintenance performance might reveal underperformance. Chapter 3 will show that literature's maintenance performance indicators recommend starting a root cause analyses to reveal the cause. Chapter 4 develops the MPM approach that is linked to the managerial possibilities to improve effectiveness and efficiency of maintenance. The result is a MPM approach that is linked to the 'maintenance control panel'. All managerial maintenance decisions are valued. The valuation indicates the performance contribution to overall performance (costs, delay and/ or downtime). These insights can be used to:

1. Generate feedback on the carrying out of the maintenance plan. The operational part of maintenance is required for controlling maintenance performance. Insights in current processes are required to evaluate the drivers of performance.
2. Prioritise all possible improvements based on their (under)performance contribution.

The relevance of optimisation depends on the value of the improvement project. The value does not guarantee improvements. Further assessment is required. The assessment evaluates the managerial and technical possibilities to succeed. The quality of solutions depends on the available information. Over time, operational data and technological innovation become available. A systematic periodic review is required to incorporate latest information.

2.3 Overview MPM and vessel management services

MPM supports maintenance evaluation for external and internal functions. The link of MPM to Fugro OpCos' profit is visualised in Figure 4. The MPM results need to identify the performance gaps. Revealing performance gaps requires insights in both the optimal organisation of maintenance and the possibilities to optimise maintenance performance. The possibilities to optimise maintenance are involved with maintenance engineering concepts. Moreover the results of the concepts needs to be carried out as planned. Details on maintenance performance drivers are required to minimise the effort to identify the causes of underperformance. The MPM results are rooted in the insights to achieve the optimal organisation of maintenance, visualised by the tree growing on the soil of optimality. Chapter 4 develops the necessary insights to grow the tree. The four steps to maximise the profit of the OpCo are shortly mentioned.

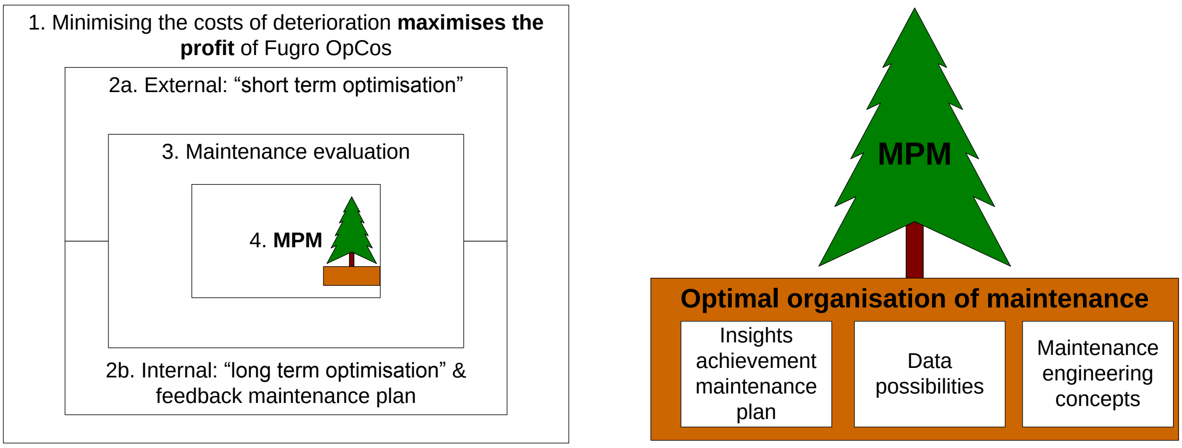

Figure 4 The research' MPM approach

1. The goal is to reduce the expected maintenance costs in order to increase OpCo's profit

2. Optimality minimises expected costs
a) *external*, measure maintenance quality, aligning maintenance plans with budgetary limits

b) *internal*, feedback to carry out the maintenance plan, improvement projects minimise long term expected costs

3. Maintenance evaluation assesses the MPM results and integrates other sources of information required to decide on improvements

4. MPM supports the maintenance evaluation by showing the performance gaps and the costs involved with all maintenance decisions.

This research focuses on the definition of MPM to support FMS maintenance evaluation. The comprehensive maintenance approach identifies the possibilities to influence performance. The MPM results value the possibilities.

3 Review MPM literature

Performance measurement is defined as the process of quantifying the efficiency and effectiveness of actions (Neely et al., 1995, P80-81). Consequently MPM should quantify the efficiency and effectiveness of maintenance. This chapter is about the difficulties with current maintenance performance measurement (MPM) literature. MPM literature's usability to support maintenance evaluation in order to improve maintenance is limited.

Section 3.1 identifies the struggle of MPM literature with developing practical applications. Section 3.2 shows that it is not practical to start at strategic objectives when improvement of maintenance is the objective. Section 3.3 discusses a set of common used performance indicators. Section 3.4 provides the conclusions.

3.1 Introduction MPM literature

This section starts with four observations of literature.

Firstly, Simões et al. (2011) have reviewed 251 articles published from 1979 to 2009 on maintenance performance. They have concluded that future research should aim at solidifying theoretical constructs and developing more practical applications. In the same year, Muchiri et al. (2011, P302) have stated that future research should aim at how maintenance performance indicators (MPIs) are effectively used to drive performance improvement in practise. The lack of and need for practicality of maintenance research has already been stated by Scarf (1997). Besides, Scarf (1997, P493) states that success of any model can only be measured in terms of impact on the real maintenance problems. Therefore it is remarkable that there has not been developed any MPM approach explicitly linked to the effectiveness and efficiency of maintenance.

Secondly, performance indicators should highlight opportunities for improvement. The ultimate performance indicator points to a solution (Wireman, 2005, Pvii). Since the observation that maintenance is not optimal is not the hard part, the statement that the *ultimate* performance indicator points to a solution is not very hopeful. Further, Wireman's (2005, Pviii) statement that rule number 1 is to tie the maintenance performance indicator to the long range corporate vision raises doubts. Long term corporate vision is not about dealing with relevant deterioration, while effective maintenance is (Dekker, 1996, P235-236). Corporate vision seems to be far away from dealing effectively and efficiently with daily deterioration of equipment. Of course, budgets are related to strategy (Pintelon & Gelders, 1992, P306-307); but it reveals little about *how* to achieve effectiveness and efficiency. The link to deterioration at equipment's level is not found in the studied MPM literature of Tsang et al. (1999), Liyanage & Kumar (2003), Parida & Kumar (2006), Muchiri et al. (2011) and Van Horenbeek & Pintelon (2014), and only partly linked in Weber & Thomas (2005).

Thirdly, according to Dekker (1996, P235-236) optimisation models provide the best decision given the available information involved with the problem at hand. As available information increases, the definition of optimal performance is changing. This could be captured by changing the strategic objectives. However, this is usually not driven by mathematical optimisation of expected cost minimisations. It is driven by benchmarking or other qualitative ways of deriving objectives of strategic goals (Neely et al, 1995, P103-108; Kutucuoglu et al., 2001; Parida & Kumar, 2006, P243-246; Van Horenbeek & Pintelon, 2014). Moreover, the definition of performance seems to be inherently related to gathering data, but maintenance performance measurement literature is not about the identification of data. Not a single paper in our bibliography has provided a list of data required to determine performance measures.

Fourthly, MPM results that lack a clear link to solving deterioration are potentially harmful. When the link lacks, the decision to initiate actions to improve the performance indicator has not integrated the effect on maintenance effectiveness. Sherwin (2000, P146) stated the following on dimensionless ratios: "… such overall comparisons can too easily be doctored by ambitious managers, and in any case distract attention from the need to gather data at the component level, analyse it and optimise the schedules." The maintenance performance indicators not linked to the effectiveness of maintenance are dimensionless.

The lack of practical tools, the aim for achieving strategic goals, and lack of identification of data can be connected. To start, companies' strategic objectives are not focused on deterioration, while effective maintenance is dealing with relevant deterioration. Therefore the primary focus on the link with strategy is doubtful. The result of strategy focused MPM provides maintenance performance related numbers. However, these MPIs are pointing to starting root cause analyses. This will be elaborated on in Section 3.2.

3.2 Result of strategy as primary MPM objective

MPM literature does not provide a method to construct a practical MPM tool. A common factor is that company's strategy takes a prominent place in MPM literature (among others; Pintelon & Gelders, 1992; Neely et al., 1995; Tsang et al., 1999; Kutucuoglu et al., 2001; Wireman, 2005; Parida & Kumar, 2006; Muchiri et al., 2011; Van Horenbeek & Pintelon, 2014). The resulting MPIs of the strategy focused MPM approach are discussed, because alignment with company's strategy is not bad in itself.

Pintelon & Gelders (1992, P306-311) discussed managerial maintenance decision making extensively. They discussed different management levels, corrective and preventive maintenance, planning and resource allocations. It was in a time that little had been found on performance reporting (Pintelon & Gelders, 1992, P311) and in a time that computer support seemed to solve the lack of data issue (Pintelon & Gelders, 1992, P313). Their prediction that quantitative techniques would solve all operational, tactical and strategic maintenance issues did not turn out to be right. In general there is a chronic lack of data to optimise maintenance automatically. Nevertheless, their statement: "In order to avoid suboptimization, maintenance management objectives should be derived from the company's objectives." seems to have had a large impact on the development of MPM literature (Pintelon & Gelders, 1992, P306-307).

Maintenance objectives are often derived of strategy. Consequently MPM is not measuring whether maintenance is effectively and efficiently organised, but whether strategic goals are achieved. Maintenance is considered to be a black box. The suggestion that quantitative models would take care of the optimisation of (the black box of) maintenance (Pintelon & Gelders, 1992; Sherwin, 2000), neglects a way to deal with the lack of data. The current functionality of the MPM results is starting root cause analyses to identify what caused the underperformance (Muchiri et al., 2011, P301). The importance of properly carrying out the maintenance plan is seldom integrated in the performance outcomes. When the maintenance plan is not carried out according to the plan, it is not measurable whether the maintenance plan or maintenance organisation has been deficient.

Van Horenbeek & Pintelon (2014) have identified over 100 performance objectives at the operational level in literature, shown in Appendix III. Figure 5 visualises the result of the MPM approach that aligns maintenance MPIs to strategic objectives of maintenance (Van Horenbeek & Pintelon, 2014).

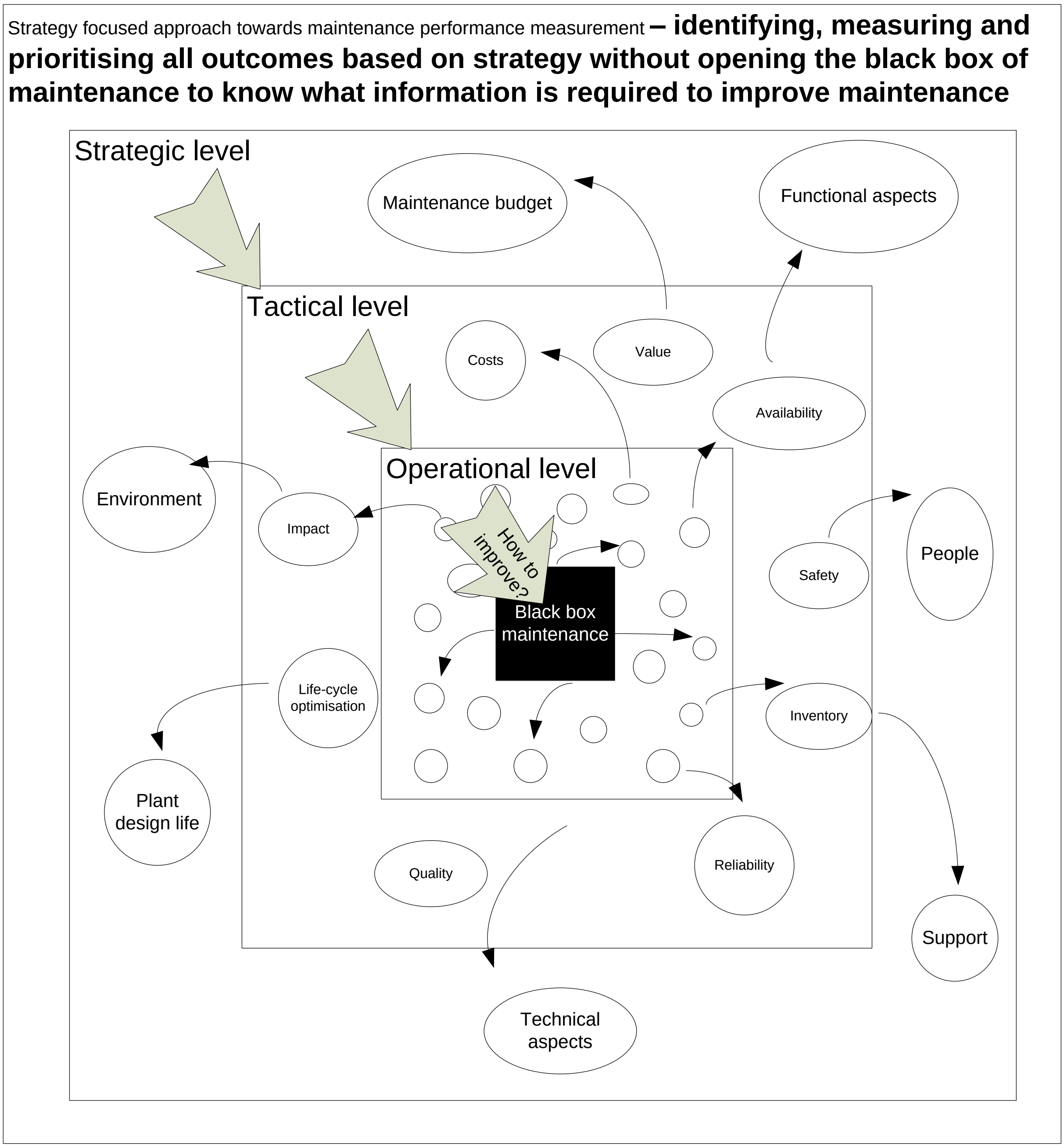

Figure 5 Visualisation of company's strategy as basis for MPM

The managerial possibilities to influence maintenance are not revealed (black box) in current strategy driven MPM. The MPI is not linked to a managerial possibility to influence performance. The recommendation is to start a root cause analysis.

A set of indicators that is used for strategy driven MPM is discussed in the following section. It shows the limitation of literature's resulting MPIs.

3.3 Leading & lagging indicators

Muchiri et al. (2011) have provided promising lists of MPIs, namely lagging and leading indicators. Leading indicators are linked to organisational steps of maintenance and lagging indicators are linked to results of maintenance. The leading indicators have integrated economic cost indicators and technical indicators related to equipment.

The leading indicators are derived from key steps for the maintenance process: work identification, work planning, work scheduling and work execution (Weber & Thomas, 2005; Muchiri et al., 2011). They focused on the organisation of maintenance, without integrating the effectiveness and efficiency of dealing with deterioration. The lacking link to deterioration (effectiveness) or costs (efficiency) of the leading indicators does not support revealing the level of effectiveness or efficiency.

Table 1 shows an indicator per category of leading and lagging indicators. Muchiri et al. (2011) their commonly used performance indicators are shown in Appendix III. Of interest is the following: what does the indicator tell about the efficiency and effectiveness of dealing with deterioration? The answer is: it depends on the actual deterioration and the possibilities and corresponding costs to cope with deterioration preventively and correctively. The actions to improve the performance is not even mentioned.

Category	Measures/ indicators	Units	Description
Work Identification	Percentage of Proactive work	%	(Man-hours envisaged for proactive work)/ (Total man hours available)
Work Planning	Quality of planning	%	(Percentage of work orders requiring rework due to planning)/ (All work orders)
Work Scheduling	Schedule realisation rate	%	(Work orders with scheduled date earlier or equal to late finish date)/ (All work orders)
Work Execution	Mean Time To Repair (MTTR)	Hours	(Total Downtime)/ (No. of failures)
Equipment Performance	Availability	%	Uptime/ (Uptime + downtime)
Cost Performance	Percentage cost of Supplies	%	Cost of Supplies/ Total Maintenance Cost

Table 1 Examples performance indicators MPM literature

When trying to assess any objective a general understanding of the underlying processes and possibilities to improve the performance indicator is required. First category indicators reveal whether maintenance is performing well: e.g. 0% of the work requires rework due to planning, 100% schedule realisation rate and 100% availability. Second category depends on the quality of the equipment: the ‘mean time to repair’ is better when the time is reduced, but strongly depends on the maintainability of the system. The third category really depends on the situation, like percentage of proactive work and percentage cost of supplies.

When considering how to improve the three indicators that reasonably indicate good performance, one has to think about the following before he can initiate actions:

- *Quality of planning:* When the planning is regarded as the cause of rework? What kind of jobs required rework due to planning? Was the planning too ambitious?
- *Schedule realisation rate:* What is the cause of the delay of the job? Missing job supporting resources? Unachievable planning? Lacking capacity?
- *Availability:* what is the cause of the downtime? Could it been prevented? What activities took a lot of time during the downtime: diagnostics of the failure? Repair preparations? The repair job? The testing whether the repair had been successful?

In short, a manager cannot decide something different than starting a root cause analysis. The following steps are required for a relevant maintenance improvement by a root cause analysis:

1. Determine what effective and efficient maintenance would mean for the MPI given available information.
2. Determine what the cause of the deficient MPI is.
3. Check for possibilities to improve the MPI.
4. Select the best possibility to improve the MPI.

This research develops an alternative MPM approach. This MPM approach starts on identifying the comprehensive set of possibilities to fill the performance gaps. Corresponding relevance (impact on performance) of the possibilities determine the necessity to initiate the improvement project. The first three steps of the root cause analyses are skipped.

3.4 Conclusions

The lack of practical MPM tools is caused by ignoring the managerial possibilities to improve maintenance performance. Maintenance performance depends on the efficiency and effectiveness of dealing with deterioration. Corporate strategy is not linked to the possibilities to deal with deterioration. Therefore MPM literature's focus on the alignment of maintenance objectives with corporate strategy is inefficient. MPM literature's recommended root cause analyses are time consuming.

The main deficiencies of MPM literature's resulting selections of performance indicators are the following:

- Not showing maintenance efficiency and effectiveness
- Not linked to component level information for maintenance plan improvements
- Not able to identify causes of lacking performance
- Not linked to coping with deterioration
- Decision making without link effectiveness is risky
- Hard to implement as required data is not included

MPM results are supposed to support the maintenance evaluation in order to support internal and external purposes (see Section 2.3 for the functional overview of MPM). MPM should measure the effectiveness and efficiency of dealing with deterioration. Literature's MPM approach is not even linked to the effectiveness and efficiency of maintenance. An MPM approach that starts at the possibilities to influence maintenance is developed in the following chapter.

4 Development MPM approach linked to managerial possibilities

Chapter 3 has shown that MPM literature focuses on measuring maintenance outcomes regardless the possible managerial possibilities to influence maintenance performance. Literature's MPM approach is limited to revealing *that* maintenance needs to be improved, not *how*. Maintenance engineering (ME) shapes the organisation of maintenance. Maintenance evaluation assesses the performance of the maintenance organisation of dealing with deterioration. Optimal organisation is achieved when the costs of deterioration are expected to be minimal.

Section 4.1 introduces the research' approach of MPM. Section 4.2 is about the relation of maintenance evaluation to the maintenance activities. Section 4.3 describes the objective of the improvement projects initiated by the performance measurement. Section 4.4 elaborates on the content of the maintenance evaluation. Section 4.5 shows an overview of the maintenance job required supporting resources. Section 4.6 provides a list of maintenance performance basics for validating any performance measurement tool. Section 4.7 derives the maintenance decisions and corresponding performance indicators. Section 4.8 concludes the chapter.

4.1 Approach performance measurement

Maintenance performance depends on the effectiveness and efficiency of dealing with deterioration. A maintenance engineering (ME) concept prescribes how to optimise maintenance performance of a specific factor of maintenance organisation given the available information. The result of applying a ME concept is the maintenance setting that is expected to minimise costs of deterioration. Optimisation is about solving optimisation problems. Maintenance is about minimising the costs of deterioration, so the optimisation involves is related to cost minimisation. Maintenance evaluation interprets MPM results to assess the performance of the ME concept. The ME concepts in the maintenance evaluation are illustrated in the following Section 4.2.

Maintenance engineering literature has discussed a wide range of maintenance organisation related topics. This includes design methodologies, maintenance planning, sensor and signal processing and service logistics (Takata et al., 2004; Jones, 2006). Maintenance optimisation requires the gathering and analysis of data at the component level in order to optimise the equipment's maintenance plan (Sherwin, 2000, P146).

The importance of economic trade-offs in maintenance decision making is often mentioned in maintenance literature (Dekker, 1996, P229-236; Gits, 1992, P221-225; Scarf, 1997, P496; Sherwin, 2000, P145-146; Jones, 2006 P1.6). Moreover money is the language of higher management (Sherwin, 2000, P145). Maintenance decisions involved with the highest costs are of highest interest. The value of an improvement project is illustrated by the current costs involved. The current costs can be improved by reorganising the involved maintenance activities. It is required that the improvement project is expected to be profitable (Dekker, 1996, P235-236).

Insights in the current costs of maintenance are required to estimate the profitability of improving project and the equipment's maintenance plan.

4.2 Maintenance & maintenance evaluation

Takata et al. (2004, P645)'s overview of maintenance activities provides a basis for the role of MPM. Maintenance should involve the following six activities (Takata et al., P645-649):

1) **Maintainability design**

2) **Maintenance strategy planning**

3) **Maintenance task control**

4) **Evaluation of maintenance results**

5) **Improvement of maintenance**

6) **Dismantling planning and execution**

The maintenance activities are explained with respect to maintenance performance:

Step 1, the design determines the maintainability and failure behaviour of the equipment. The design has the highest impact on the total maintenance costs during the lifespan of equipment. Jones (2006, P5.8-5.11) emphasises the need to minimise the required maintenance job supporting resources in the maintainability design phase. The design for maintenance is involved with ME concepts.

Step 2, initially there is no operational data available for maintenance strategy planning. Therefore initial maintenance engineering relies on suppliers' provided information on failure behaviour and recommended maintenance. The maintenance strategy and technical maintenance possibilities form the basis for the maintenance plan to deal with expected deterioration. Literature provides different methodologies to select maintenance strategies (among others; Gits,1992; Coetzee, 1997, P47-51; Löfsten, 1999; Arunraj & Maiti, 2009). However, the available information determines the quality of the maintenance plan. The quality of the initial maintenance plan determines the need for future improvements. ME concepts are available for maintenance strategy planning.

Step 3, the maintenance task planning involves the organisation of resources in order to carry out the maintenance plan. ME concepts are available for the organisation of resources. The job supporting resources, which will be elaborated on in Section 4.5, are required to finish a job. Unavailable resources hinder the achievement of the maintenance plan. To be able to improve the maintenance plan, the first step is to carry out the maintenance plan. MPM needs to support the maintenance evaluation by revealing whether the maintenance plan is achieved.

Step 4, maintenance evaluation provides feedback on the previous 3 steps. Feedback should be given on the achievement of the maintenance plan, the maintenance plan and the design of the equipment. MPM supports maintenance evaluation. The ultimate MPIs point to solutions, but Chapter 3 showed that the standard MPI recommends a root cause analysis.

Step 5, technological innovation and gathering of data should be exploited to improve maintenance. Maintenance evaluation should be a periodic activity to ensure achievement of the maintenance plan and optimal execution of ME concepts involved with high (risk on) costs.

The interest in mathematical modelling for the maintenance engineering processes is stated almost 20 years ago by Dekker (1996, P232-233). Recent promotions in the field of Failure Mode and Criticality Effect Analyses (Braaksma 2012) and spare parts inventories and level of repair analysis (Basten, 2010) indicate that the researcher's interest is still there. Moreover maintenance is a hot topic in improving business at for example the Service Logistics Summit (SLS, 2014). However, the link to the minimisation of effects of deterioration is not explicitly made. There is a need for an overview of costs to prioritise the ME concepts. The assessment of the current quality reveals the need for an improvement project.

4.3 Ideal situation: effective and efficient maintenance

MPM literature's objective is to assess whether maintenance performance is good at the high strategic level. This enables global comparisons of performance (Raouf & Ben-Daya, 1995, P10-14; Tsang et al., 1999, P710-712; Muchiri et al., 2011; Van Horenbeek & Pintelon, 2013), but it does not reveal details on the effectiveness and efficiency of maintenance. When one is able to quantify effectiveness and efficiency gaps, one is able to estimate the value of maintenance improvements. The value of maintenance is formed by costs that would have occurred otherwise (Dekker, 1996, P231; Jones, 2006, P5.6), i.e. when no (preventive) maintenance is carried out. There is also no practical approach of determining maintenance value.

Increasing efficiency and effectiveness is related to reducing the effects of deterioration. Efficient and effective maintenance is considered to be optimal. Thus, performance measurement requires proper measurements to assess whether maintenance is effective and efficient. This section defines effectiveness and efficiency of maintenance.

4.3.1 **Definition effectiveness - condition equipment**

- Maintenance actions can only be effective when addressing relevant deterioration (Dekker, 1996, P235).

The deterioration influences the condition of the equipment. Minimising the effect of deterioration is relevant when deterioration increases the risk on affecting the service delivered. For example, causing downtime of vessels or reducing quality of production. The effect on minimising the effects of deterioration determines the effectiveness of the maintenance job.

It is hard to assess whether the current maintenance plan is most effective. Nevertheless, it is clearly ineffective to carry out extensive maintenance on equipment that is in good condition. A job that does not improve equipment's condition is considered as ineffective.

The added value of condition measurement technology depends on the decreased risk on downtime, the reduction of maintenance jobs and the costs of the technology. When there are no sensors available to measure threshold crossings, the determination of the condition relies on expert's assessments.

4.3.2 **Definition efficiency – costs comparison**

- Maintenance efficiency depends on the realised costs with respect to the total minimum costs involved with the best possible maintenance plan (Takata et al., 2004, P644).

The need for preventive and corrective maintenance is interdependent, i.e. when deterioration is effectively taken care of preventively; less corrective repairs and downtime are expected. Besides, when corrective measures are quick and cheap, the need for extensive preventive maintenance programs is reduced (Löfsten, 1999, P716-721). Further, changes in the speed and flexibility of the supply chain to deal with breakdowns influence the need for preventive maintenance

Consequently, the determination of what is best requires detailed information on different policies of both preventive - and corrective maintenance. The best policy is involved with the lowest total costs (including costs of downtime). The potential value of maintenance is the best policy's total costs minus the total costs of doing no preparations at all.

4.4 Maintenance evaluation – content

The main points of the previous sections related to the maintenance evaluation are:

1) The possible improvement projects (apply a ME concept) that need to fill a effectiveness and efficiency gaps.

2) The need to check the achievement of the maintenance plan.

Based on Takata et al. (2004, P646-647) the distinction between the technical and managerial evaluation is made.

The technical evaluation is related to selecting the maintenance strategy to deal with deterioration. The technical evaluation recommends initiating equipment level improvements when maintenance is ineffective. As the maintenance plan determines the magnitude of maintenance costs, an improvement project can be initiated when the equipment's maintenance costs are considered as too high.

The managerial evaluation is about carrying out the maintenance plan. This involves two steps. Firstly the preparations of the job supporting resources and secondly the execution of the maintenance plan.

The maintenance evaluation is not primarily aimed on identifying design improvements. Periodic maintenance evaluation is about reducing the effects of deterioration of equipment in order to improve performance. However, when maintenance is effective and efficient, it can still be considered as unsatisfying. The possibility left is to change the design.

4.5 The maintenance job supporting resources

This section identifies the building blocks of maintenance. The maintenance job requires job supporting resources to finish a job. The resources are directly linked with costs. Therefore details are required to control the total costs of deterioration. Pintelon & Gelders (1992, P310) have identified personnel, materials, repair shop and information as the supporting resources for maintenance. Jones (2006, P13.7) has split the materials into spare parts, repair materials, tools and support & test equipment, leading to the following five job supporting resources:

1) Trained personnel
2) Spare parts & repair materials
3) Facilities
4) Technical documentation
5) Tools, support & test equipment

When availability of the system is required for services or production, one more building block is required to organise maintenance jobs. The costs of downtime need to be taken into account. Moreover, 'time' is required for any job. The supporting resource 'time' is the 6th supporting resource:

6) Time

Time related improvement projects are often related to one of the other 5 job supporting resources. E.g. a project would be improving the planning to improve repair capacity (trained personnel) utilisation or enable sharing set up costs (facilities).

4.6 Overview basics maintenance performance measurement

Primarily based on Dekker (1996), Sherwin (2000), Takata et al. (2004) and Jones (2006) the following basics of maintenance performance measurement are identified:

1) Maintenance improvements require gathering and analysing data at the component level to optimise the equipment's maintenance plan (Section 4.1).
2) Assess impact (savings) of improvement project versus the efforts (costs) required (Section 4.1).
3) Maintenance evaluation assesses decisions of system's design, maintenance strategy selection and maintenance task control in three feedback loops to identify maintenance improvement areas (Section 4.2).

4) Effectiveness of maintenance jobs depends on the relevancy of improving the condition of equipment (Section 4.3).

5) Efficiency of maintenance depends on the total minimum costs of maintenance (Section 4.3).

6) Maintenance performance evaluation consists of a technical and a managerial component (Section 4.4).

7) The managerial evaluation includes the achievement of the maintenance plan and the distribution of costs over the job supporting resources (Section 4.4).

8) The technical evaluation includes the effectiveness to deal with deterioration and the costs involved (Section 4.4).

9) Changing the system design is an expensive possibility when optimal maintenance strategy planning and maintenance task control are not satisfying (Section 4.4).

10) Total maintenance costs consist of job supporting resources, namely trained personnel, spare parts, facilities, technical documentation, tools and time (Section 4.5).

These ten points identify the basics of maintenance performance evaluation. The points reveal the relation of maintenance evaluation to the maintenance activities, the definition of optimal maintenance (effective and efficient) and the content of maintenance. The maintenance evaluation requires MPIs to support selecting improvement projects. Improvements concern effectiveness and efficiency gaps and the achievement of the maintenance plan.

4.7 Managerial decision areas and performance indicators

Optimal organisation of maintenance is effective and efficient. When the organisation of maintenance is optimal, the costs of deterioration are minimised. The goal is to set up a MPM approach that supports achieving an optimal organisation of maintenance. All possibilities to optimise maintenance are required. The decision to optimise a part of a managerial decision area is called a managerial decision.

Section 4.7.1 provides a framework of a comprehensive set of managerial possibilities to improve dealing with deterioration. Section 4.7.2 integrates the job supporting resources in the framework in order to derive the performance indicators. Section 4.7.3 summarises the performance indicators per managerial decision area in a general overview.

4.7.1 **Framework managerial decisions**

This section shows that a comprehensive approach of maintenance evaluation deals with:

- The corrective and preventive organisation to deal with deterioration.
- The levels to improve maintenance organisation.
- The building blocks of maintenance: the job supporting resources.

Maintenance is about dealing with deterioration. Dealing with deterioration can be done preventively or correctively. Preventively and corrective organisation differ. Preventive maintenance is basically plannable, critical failures are not planned. Löfsten (1999, P716-721) emphasises the necessity of the insights in the preventive and corrective maintenance possibilities and corresponding costs in organising maintenance. *However, MPM literature does not systematically distinguish the effect of preventive and corrective maintenance in MPM.* The result is that it is not clear whether performance can be improved by the plannable maintenance or the failure preparations.

The technical evaluation is involved with determining the best way (effective and efficient) to deal with equipment's deterioration (Gits, 1992; Löfsten, 1999; Takata et al., 2004). This depends on the technical possibilities to deal with deterioration, available data to model failure behaviour of equipment and corresponding costs of preventive and corrective maintenance. Maintenance engineering (ME) provides different methodologies to optimise dealing with deterioration.

The managerial evaluation requires job level information and resource level information. Job level information is required to be able to control the achievement of the maintenance plan. Moreover, job level information is required to identify the distribution of costs. Resource organisational changes are required when the total costs and delays involved with a job supporting resource are not satisfying. Maintenance engineering (ME) provides different concepts to optimise the organisation of resources.

Figure 6 shows the framework of managerial decision areas (MDA) for maintenance evaluation.

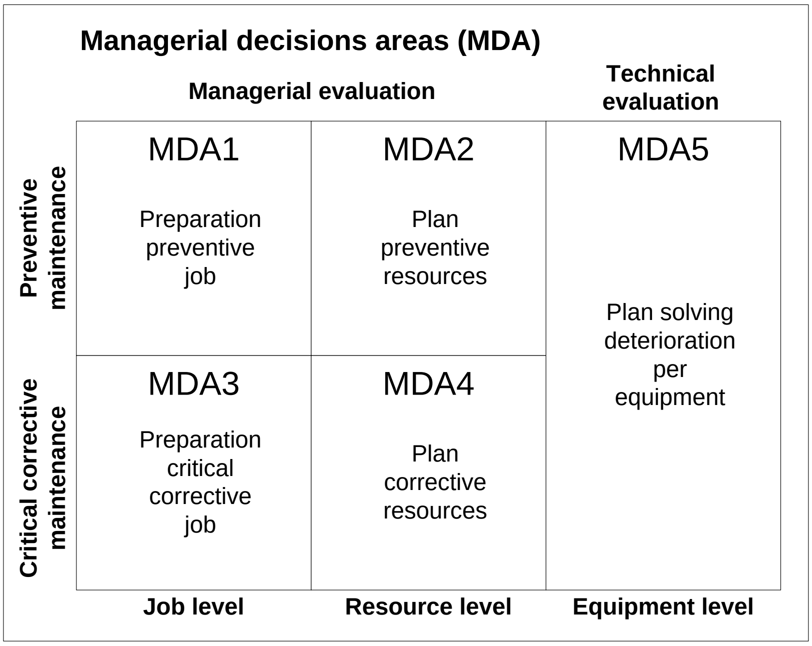

Figure 6 Overview managerial decision areas

The improvements concern the organisation of job supporting resources. The job supporting resources are the cost driving building blocks for maintenance jobs. The managerial decision areas are used in Section 4.7.2 to set up the maintenance performance indicators (MPIs).

The framework covers the managerial possibilities to improve maintenance performance:

- The equipment level maintenance plan describes what job supporting resources are required to minimise the effects of deterioration
- The resource level covers the organisation of job supporting resources for maintenance jobs.
- The job level is actually dealing with deterioration using the job supporting resources.

Job level information is required to assess the correctness of the assumptions made in the ME of the resource and equipment level. Evaluation of the processes is twofold:

Firstly, the implementation of the ME recommendations need to be checked for achievement. E.g. when the ME results prescribe spare part X15 needs to be on stock, but this is not carried out, the solution is to improve the implementation of the ME solution.

Secondly, the assumptions on deterioration and costs used to optimise the cost minimisation problems have to be evaluated. When data shows that the assumptions (e.g. expected costs, deterioration) are wrong, the cost minimisation problem needs to be solved with a new set of assumptions based on operational data.

This thesis' MPM tool does not integrate predictions. Next generation MPM could compare the model's expected costs and deterioration with the actual costs and deterioration to reveal performance gaps. Statistical significance of differences reveals that the maintenance setting is sub-optimal. The expected savings determine whether the ME concept should be applied.

4.7.2 **Maintenance performance indicators per MDA**

The managerial decision areas (MDA) are discussed to identify a comprehensive set of MPIs to reveal effectiveness and efficiency gaps. When the optimum requires optimisation of a cost minimisation problem, then the total costs involved are provided to identify the value of the part of maintenance. Part of the decision to initiate an improvement project is the expectation that the benefits of the project need to exceed the costs (Dekker, 1996, P229-P236; Gits, 1992, P221-225; Scarf, 1997, P496; Sherwin, 2000, P145-146; Jones, 2006 P1.6).

Not all performance indicators are involved with costs. A need to check for the realisation of the maintenance plan is required. Time related performance indicators are also required. The MDAs indicated by Figure 6 on the previous page are discussed from 1 to 5.

MDA1) Preventive maintenance – job level

Carrying out the maintenance jobs according to the plan is required to assess the effectiveness of the maintenance plan. Job delays are considered to be performance gaps. The delay of a job supporting resource provides information to improve future job preparations.

Cost improvements are not considered relevant at the job level. The job costs what it costs and the job supporting resources are prescribed by the maintenance plan. All 6 job supporting resources could be unavailable. The following performance indicators show the effectiveness gaps in the time unit that is most appreciated:

1) Delay personnel
2) Delay spare parts
3) Delay facilities
4) Delay technical documentation (TD)
5) Delay tools
6) Delay maintenance opportunity (MO)

The objective of the performance indicators is no delay. An optimal maintenance organisation is expected to carry out the job in time.

Consider an overdue job. One of the required job supporting resources is unavailable. Filling the performance gap for future similar maintenance jobs requires an improvement project to make the resource available. The first step of the improvement project is to analysis the cause of the delay.

The job could be overdue, while all job supporting resources are available at the due date. The responsible manager needs to be consulted to identify the cause of the underperformance.

MDA2) Preventive maintenance – resource level
Available resources are required to carry out the preventive maintenance job. Optimal organisation of resources makes sure that job supporting resources are available to finish the jobs before the due date with a minimal amount of costs.

The maintenance manager could decide to initiate an improvement project towards the job supporting resource when:

- The maintenance jobs are often delayed due to the job supporting resource, because improving effectiveness of the maintenance schedule requires the maintenance jobs to be finished in time

- The costs are worth optimising to improve efficiency

Firstly, all 6 types of job supporting resources could be unavailable when a job is delayed. The frequency of lacking job supporting resources at the due date (DD) indicates the possibility that the resource level plan is sub-optimal. The improvement project starts at the identification of causes of the lacking job supporting resources. The performance indicators:

1) Number of delayed jobs
    a. Frequency lacking personnel at DD
    b. Frequency lacking spare parts at DD
    c. Frequency lacking facilities at DD
    d. Frequency lacking TD at DD
    e. Frequency lacking tools at DD
    f. Frequency lacking MO near DD

The optimum number of delayed jobs is 0.

Secondly, the priority of optimisation is revealed by the total costs involved. Evaluation of the corresponding level of organisation is part of the maintenance evaluation to decide starting an improvement project (solving a cost minimisation problem)

The indicators to prioritise the optimisation of job supporting resources for preventive maintenance are:

1) Costs of personnel
2) Costs of spare parts
3) Costs of facilities
4) Costs of TD
5) Costs of tools
6) Costs of time

Optimal costs of preventive maintenance job supporting resources depend on the available information to optimise the organisation (Dekker, 1996).

MDA3) Corrective maintenance – job level
Jones (2006, P4.20) identifies different stages in the repair of a failure. The downtime consists of the four stages:

- identification of failed item(s) - diagnosing time

- *the time to retrieve all job supporting resources - preparation time*

- the time to carry out the repair, including testing - repair time

- the time to continue the regular schedule - return time

Except for the time to retrieve the required supporting resources, the solution to reduce the time is technical or design related. The technical improvements of dealing with deterioration are not considered to be a primary activity of the maintenance department. Therefore the measurements are focused on the preparation time. When a maintenance department is capable to develop technical possibilities to deal with deterioration, the primary indicators could include the diagnosing time, repair time and return time.

The initial selection of job supporting resources to cope with critical failures is already made. Future preparations on the repair job level need to be improved when job supporting resources turn out to take a long time to retrieve. Future repair job preparation time of similar repairs needs to be decreased. The actual decision to make available the job supporting resource depends on the costs and the expectation of future failures. The indicators to initiate an improvement project are per job:

1) Duration to retrieve personnel
2) Duration to retrieve spare parts
3) Duration to prepare facilities
4) Duration to retrieve TD
5) Duration to retrieve tools

The job supporting resource ‘Time’ does not initiate improvements, as the critical failure initiates a maintenance opportunity instantly. The time to diagnosis and repair time are considered as technical improvements. Improving the technical approach to carry out diagnoses or maintenance is not considered as a maintenance manager’s possibility to improve performance. When it turns out that it is possible, the time to diagnosis and/ or the time to repair is a primary performance indicator.

The optimum of the performance indicators is an instant availability of job supporting resources. This is related to 0 hours of duration retrieving any job supporting resource. Nevertheless, the costs of instant availability of job supporting resources could be high. Optimising the selection of job supporting resources is involved with constraints like budget, space, expected failures, costs and delivery times.

MDA4) Corrective maintenance – resource level

Managerial decision area 4 (MDA4) is about improving the organisation of job supporting resources. When the preparation of repairs is systematically waiting for a particular job supporting resource, an improvement project could be decided. The indicators are related to:

- The total time to retrieve the job supporting resource is systematically long. The solution is not found in improving preparations for single failures (MD3).
- The costs involved with the job supporting resource are worth optimising

The total costs involved with the resources for critical maintenance are related to the efficiency of maintenance. The performance indicators are:

1) Costs of personnel
2) Costs of spare parts
3) Costs of facilities
4) Costs of TD
5) Costs of tools
6) Costs of time

Optimal total costs of corrective maintenance job supporting resources depend on the available information to solve the problem statement (Dekker, 1996), i.e. the organisation of the job supporting resource.

The possibility to reduce the costs of time can be improved by the availability of the job supporting resource for a specific repair (MDA3). Nevertheless, when a particular resource is the bottleneck frequently, the organisation of the job supporting resource can be reassessed.

The total downtime puts the time to retrieve the job supporting resource in perspective. The time diagnosis to retrieve/ prepare the job supporting resource could be reduced when the job supporting resource is instantly available. The performance indicator is indicative. Job level details are available to support the analysis of the cause.

7) Total time failures to continue schedule (total downtime)
    a. Total time diagnosis to retrieve personnel (resource preparation time)
    b. Total time diagnosis to retrieve spare parts
    c. Total time diagnosis to prepare facilities
    d. Total time diagnosis to retrieve TD
    e. Total time diagnosis to retrieve tools

The optimum of the performance indicators is 0 hours duration of retrieving the job supporting resource for all critical repairs. However, job level analysis of failures should identify the bottleneck preparations when multiple job supporting resources are unavailable.

MDA5) Maintenance plan – equipment level
Managerial decision area 5 is about the technical evaluation. The technical evaluation concerns the best fit of the maintenance strategy and corresponding plan with the equipment's deterioration. The economic evaluation is inherent to the strategy selection (Gits, 1992, P224-225; Löfsten, 1999, P716-721). Reassessments of the maintenance strategy and plan are of higher priority when the involved costs increase.

The original preventive maintenance schedule and required selection of spare parts and tools for breakdown management are usually recommended by suppliers. Improvements might be available when:

- Operational data is gathered to support deterioration modelling, identify maintenance possibilities to cope with the deterioration and optimise costs of different maintenance strategies/ plans

- Technological innovation provides new methods to cope with deterioration.

The improvement projects are of interest for equipment that is involved with high maintenance costs. One should be well aware that data driven projects and technological innovation do not guarantee lower costs. (Dekker, 1996, P235-P236)

Previously, we have mentioned some factors which are important to assess whether improvements of the current maintenance plan could be beneficial. We summarise:

- An indication on the job's effect on the condition of the equipment reveals whether the maintenance job has been effective and therefore necessary.

- Failures due to delayed preventive maintenance are probably solved by timely preventive maintenance instead of changing the maintenance plan (MDA1)

- The downtime of critical failures that could be solved by availability of job supporting resources needs to be taken into account (MDA3). E.g. you don't want to change the maintenance plan if the availability of a single spare part would have reduced 30 days of downtime.

The corresponding performance indicators per piece of equipment are:

1) Total costs
2) Frequency negligible effect condition equipment
3) Total delayed preventive maintenance jobs
4) Number of critical failures
    a. Duration failure to continue schedule (total downtime)
    b. Duration diagnosis to start job (preparations)

The performance indicators' objectives are discussed:

- When the costs increase, the importance of optimising the involved problem statement (fit of maintenance strategy and maintenance plan with the deterioration) increases. The optimal total costs depend on the equipment specific problem statement's solution.

- When maintenance is effective the maintenance jobs improve the condition of the maintained equipment. The objective is 0 jobs with a negligible effect on the condition of equipment.

- To make sure changing the maintenance plan is the best solution to effective and efficient maintenance, the preventive maintenance jobs need to be carried out in time. The objective is 0 delayed jobs.

- The number of critical failures indicates the reliability of the equipment and puts the repair performance of the organisation in perspective. The *impact* of critical failures needs to be reduced, as these interfere with the commercial schedule. The objective is 0 hours downtime. Thus, reducing critical failures is not an objective; reducing downtime is.

- The preparations' time indicates the time that could be reduced by improved preparations (MDA3/ MDA4).

4.7.3 **Overview performance indicators per managerial decision area**

The performance indicators are shown per managerial decision area in Figure 7. The job level performance indicators are registered per job. Structured analyses of job level performance indicators can be sorted on impact to identify the ineffective maintenance jobs.

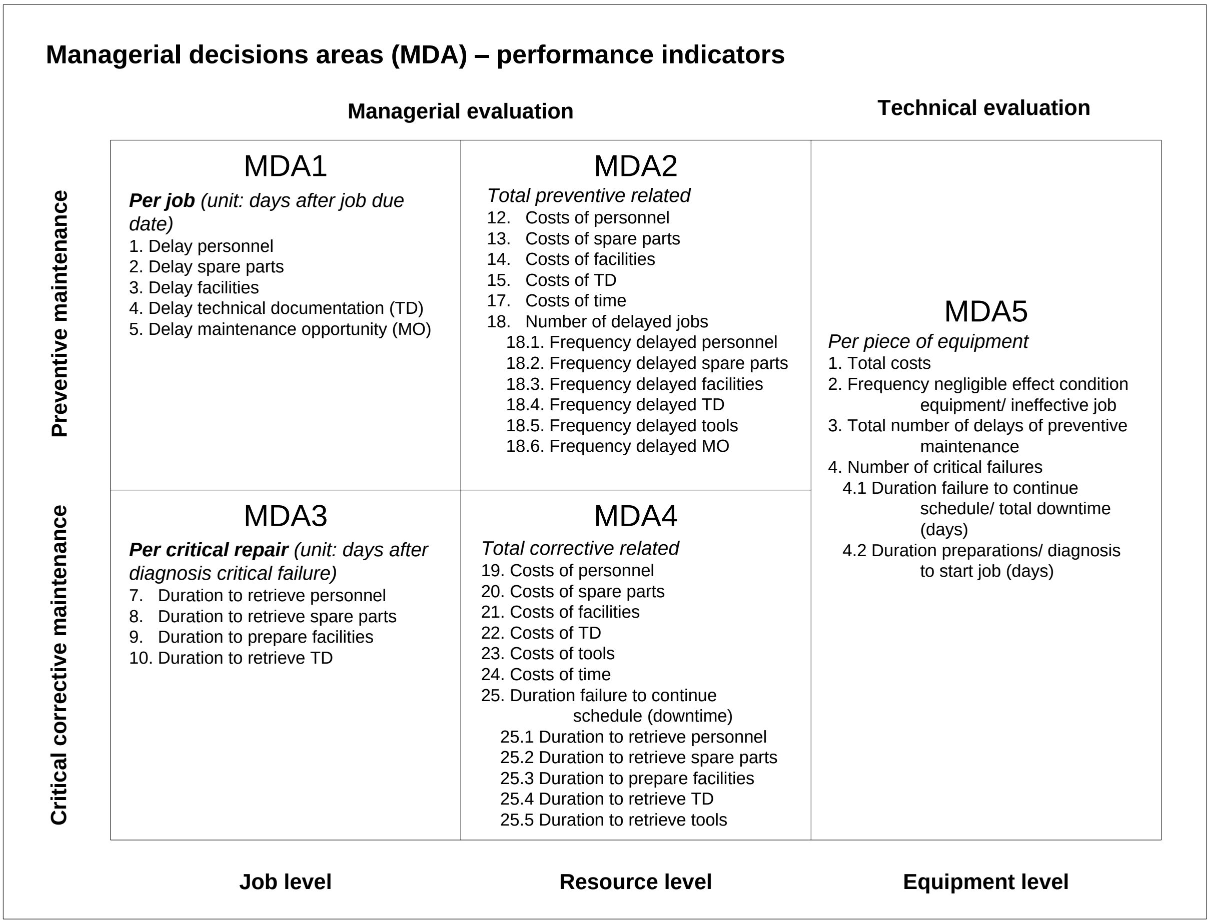

Figure 7 Overview performance indicators per managerial decision

The managerial decisions areas to initiate improvement projects include all job supporting resources and maintenance decision levels of an existing system. When solving the effectiveness and efficiency gaps would not satisfy the system's owner, the decision to change the system's design can be taken.

In short, the information required is firstly the start and due date of the preventive maintenance job. Secondly, the evaluation of the jobs requires information on the job supporting resources. Information on costs, order, delivery and usage dates are required. Thirdly, critical repairs need in addition on the information on job supporting resource, details on time. Required time entries are time of failure, time of diagnosis, repair start time, repair finish time, and the time to continue the commercial schedule.

4.8 Conclusions

The maintenance engineering literature is consulted to set up a MPM approach (the tree displayed at Figure 4, Section 2.3). The approach provides a comprehensive set of managerial decisions to achieve effective and efficient maintenance. Three core basics are identified to set up a comprehensive set:

Firstly, the organisation of *corrective* and *preventive* maintenance requires separate feedback to optimise maintenance performance.

Secondly, the costs and delays of a maintenance job are related to job supporting resources. All 6 resources are:

1) Trained personnel
2) Spare parts & repair materials

3) Facilities
4) Technical documentation
5) Tools, support & test equipment
6) Time

Thirdly, optimal effectiveness and efficiency is related to the available information to search for improvements for performance gaps. Managerial maintenance decisions to minimise the expected costs of deterioration are involved with three levels:

1) **Job level** – problem statement concerns the organisation of job supporting resources to finish a particular job
2) **Resource level** – problem statement concerns the organisation to efficiently organise the job supporting resource
3) **Equipment level** – problem statement concerns the optimal maintenance plan per piece of equipment. The maintenance plan prescribes the required job supporting resources to solve deterioration effectively.

Figure 7 on the previous page provides an overview of the managerial decision areas and required performance indicators. The performance indicators identify the costs, delays and duration of preparations per job supporting resource involved. The decision to initiate an improvement project depends on the maintenance evaluation.

The construction of a decision support tool requires details of the installed system. Chapter 5 identifies the specifics of FMS.

MPM supports maintenance evaluation for external and internal purposes. Effective maintenance performance measurement points to solutions when performance is not optimal. Or as Wireman (2005, Pvii) stated, the ultimate performance indicator points to a solution to improve maintenance performance. An overview of all possible managerial maintenance decisions contains all solutions. An overview of performance contribution of all decisions enables the sorting of the improvements. The most relevant solutions can be filtered. In Wireman's terms, the valuation of all managerial decisions is the ultimate set of performance indicators.

5 FMS' Maintenance Performance Measurement

Chapter 4 has constructed the comprehensive set of five managerial decision areas to improve maintenance performance. Improvements concern changes in the maintenance organisation, including the job level, resource level and equipment level. Performance is related to maintenance costs and delays of job supporting resources: trained personnel, spare parts, facilities, technical documentation, tools and time. Per managerial decision the role of the job supporting resources at Fugro Marine Services (FMS) is discussed. The result of this chapter is an overview of MPIs and corresponding data required to support FMS' decision making.

Section 5.1 provides the primary information on the six job supporting resources. Section 5.2 provides an overview of the costs related to the job supporting resources. Section 5.3 identifies the maintenance performance indicators (MPIs). Section 5.4 provides the data required to calculate the MPIs. Section 5.5 discusses the approach to prioritise the MPIs and corresponding improvements. Section 5.6 provides the conclusions of the chapter.

5.1 Job supporting resources FMS

The six job supporting resources are introduced in the following subsections. The information is gathered from the information system 'Star', maintenance procedures, operational expenditures and discussions with FMS' employees. Details on FMS' maintenance can be found in Appendix II, the baseline study. Per job supporting resource the following is of interest:

- Indication of the quality of the organisation of the job supporting resource
- Data availability and possibilities of 'Star'

The higher the quality of the organisation the lesser improvements (savings of total costs) are expected by initiating improvement projects towards the maintenance policy.

The information system 'Star' contains a lot of data. Current 'Star' reports do not support any analyses of maintenance performance. Maintenance improvements are not high on the priority list of FMS.

5.1.1 Trained personnel

Jobs are carried out by the crew or an external service provider. The crew carries out the jobs they (think they) are capable of.

Policy

- Required maintenance capacity and competences are not quantified.
- There is no clear agreement on what to outsource.

Data

- There are hour registration possibilities in Star, but not activated. There is no data on the crew activities, so examining the utilisation is not possible.
- The costs of external services are unregularly registered in Star.
- The financial administration is not linked to the maintenance jobs.

5.1.2 Spare parts & repair materials

Spare parts usage is supposed to be registered at 'Star'. The selection of spare parts aboard is based upon the suppliers' recommended spare parts. Ordering spare parts is done manually. There is no automatic replenishment system based on stock levels.

Policy

- Recommended spare parts of suppliers are prescribed. Clear spare parts usage and registration is currently implemented.
- Per preventive maintenance job the crew is supposed to make an order.

Data

- ‘Star’ does not include the value or job involved per spare part in the reports. The report only provides stock changes.
- ‘Star’ does not store the value of a spare part at the moment it is used. The value is based upon the last implemented value of the spare part.
- There is no overview of spare parts usage details.
- It is possible to manually check job reports to see what spare parts had been involved. There is no general report to get the information automatically.

5.1.3 **Facilities**

Maintenance jobs require the vessel to be at a minimum vessel status, e.g. most jobs can be carried out when the vessel is at a dry dock, while during the operation the range of possible jobs is limited. The vessel statuses are:

1. “In operation”, the job can even be carried out while the vessel is carrying out a commercial project.
2. “Sailing”, when the vessel is in transition from one place to another, the job can be carried out. Equipment that is only required for carrying out the commercial project could be involved.
3. “For anchorage”, when the vessel is laying for anchor the job can be carried out. Most regular maintenance jobs can be carried out “For anchorage”.
4. “Alongside”, when the vessel is connected to the shore, the job can be carried out. Heavy loads, like equipment or tools, might need to be brought aboard.
5. “Dry dock”, some jobs require the vessel to be laid up in a dry dock.

Also the maintenance opportunities have a minimum vessel stance. The baseline study, Appendix II, showed that a FSSV lies “for anchorage & alongside” 30% to 42% of the year, “Sailing” 12% to 26% and is “In operation” 43% to 56% of the year.

Policy

- Maintenance needs to be carried out and the chief engineer aboard is responsible to achieve the maintenance schedule.
- The maintenance schedule provides due dates. Setting the due dates does not take into account the occurrence of minimum vessel stances, dry docking jobs excluded.
- Dry dock preparations rely on the vessel superintendents. There is no centralised registration of performance beyond the budget of such dry docking periods.

Data

- ‘Star’ stores data on maintenance jobs and corresponding vessel statuses. An overview of vessel statuses over time is registered in Excel.
- It is not registered what the expected duration of the vessel status is. Consequently it is not possible to determine whether there has been a maintenance opportunity.

- The actual vessel status of a maintenance job is not registered. A check whether the crew is carrying out the right job at the right vessel status is not possible.

5.1.4 Technical documentation

The crew needs to know how equipment is supposed to be maintained. There is no separate administration of technical documentation costs, as documentation is supposed to be available. However, market developments are involved with suppliers who aim to sell more service contracts. It could affect the costs of documentation.

Policy

- Technical documentation is supposed to be delivered when new equipment is purchased.
- Retrieving proper documentation is hard when suppliers are not cooperating.
- Technical documentation is made available in 'Star'.

Data

- Not all technical documentation is available, however structured administration of unavailable documents and unwilling suppliers is lacking.

5.1.5 Tools, support & test equipment

Tools might be required to carry out maintenance jobs. Tools can be bought and be rented.

Policy

- The crew can purchase tools when required according to the maintenance plan. Tools are classified as spare parts.
- Usage of tools is not registered

Data

- Tools are registered as spare parts. Knowledge of spare parts is required to recognise the tool in the list of spare parts on stock (if registered as on stock).

5.1.6 Time

Time is required for maintenance jobs. The data storage of 'Star' does currently not support the identification of downtime causing maintenance jobs and corresponding organisation of job supporting resources.

Policy

- Since 1 January 2014 the vessel statuses over time are registered in a daily Excel report. There is no link to potentially involved maintenance jobs in 'Star'.
- Durations of any crew activities are not registered. This includes the time spent on maintenance jobs. The utilisation of crew capacity is unknown.
- Details on maintenance opportunities lack. This includes expected and actual durations of MO's, which are required for determining missed revenues (costs of unavailability/ downtime costs)

Data

- When the maintenance job is planned, the time related data is limited to the due date; when the maintenance job is finished, the time related data is limited to the finish date. This leads to:
    - The performance analysis of the maintenance planning is limited to the current overdue jobs per vessel.
    - Performance / bottleneck analyses in preparing job supporting resources are not possible
- Maintenance opportunities are not registered in ‘Star’. The expected duration of vessel statuses can be added in the daily reports in Excel.

5.1.7 Conclusions

The information system ‘Star’ is expected to be capable of storing necessary data and providing structured data in Excel compatible output. Important missing data is:

1. The time related data to assess whether the preventive maintenance plan is achieved is unavailable
2. Information on the required crew capacity and competences is unavailable
3. (Overview of unavailable technical documentation is lacking)
4. (Tools are registered as spare parts)
5. Information on maintenance opportunities is missing

The time related measures need to be solved. Details on the realisation of the maintenance plan are required. Details are required to initiate improvements of the job, resource or equipment level.

The baseline study (Appendix II) reveals that the crew is involved with significant costs, while technical documentation and tools are not. Therefore, optimising crew capacity selection is of interest and requires crew hour registration. Tools and technical documentation is no priority.

Improving the facilities is related to exploiting maintenance opportunities. Information on maintenance opportunities and corresponding vessel statuses is required.

5.2 Overview required information on distribution of costs

Figure 8 shows an overview of maintenance costs. Proper evaluation of job, resource and equipment level decisions requires the costs to be linked to jobs. High costs need to be structural when resource or equipment level improvements are initiated.

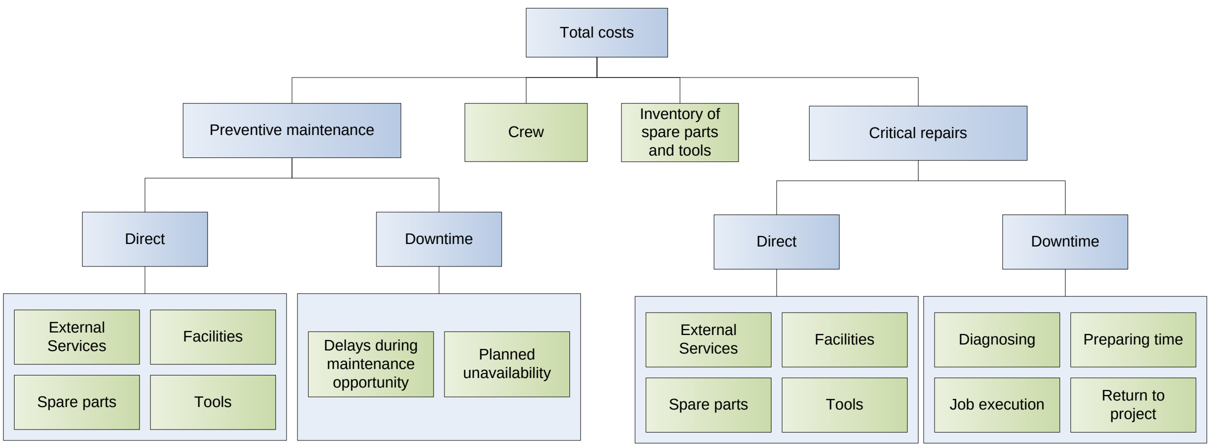

Figure 8 Tree of costs related to job supporting resources

All job supporting resources are shown in Figure 8. Valuation of the improvement projects requires the separate registration costs of preventive and corrective maintenance. Crew and inventory improvements need to account for both preventive and corrective maintenance.

The following is visualised by Figure 8 and needs to be integrated in the MPM results:

- Job level decision making requires costs and delays per job supporting resource. Resource IDs need to match other databases to identify the suppliers involved.
- Resource level decision making requires aggregated costs per job supporting resource (including missed revenues, downtime costs, due to preventive and corrective maintenance)
- Technical information is supposed to be delivered with the purchase of equipment and is therefore not included as a separate cost.
- Preventive maintenance includes the non-critical repairs. These repairs can also be carried out when a maintenance opportunity occurs.
- The vessel is available or unavailable, so there is no intermediate state of missed revenues due to deterioration. Costs for unavailability are not accounted for at FMS' financial department. Nevertheless unavailability is in potential the largest cost. The types of downtime are discussed, starting with preventive maintenance related downtime:
    - Planned preventive downtime concerns planned maintenance jobs which cannot wait for maintenance opportunities. E.g. some external service providers cannot offer the flexibility and speed to exploit maintenance opportunities. Dry docking periods concern the majority of planned downtime.
    - Unplanned downtime is related to insufficient durations of maintenance opportunities.

  Critical corrective related downtime:

    - The time to prepare the critical repair job can be influenced by changing the availability of job supporting resources. This lies within the reach of the maintenance manager.
    - Time to diagnosis and job execution time depend on technical possibilities.
    - The time required to return to the commercial project depends on the facilities nearby the project scene, which are not within the reach of the maintenance manager.
- The facilities are job specific at FMS, because the jobs are linked to a minimum vessel status. Fees might need to be paid when the vessel is anchoring or alongside in a port or in a dry dock.

5.3 Overview information per managerial decision

This section provides the information required per job. It includes the effect on the condition of equipment and the details of job supporting resources. The latter involves information on what *job supporting resource* is when *ordered, available aboard and exploited* for what *maintenance job*. Appendix IV contains an extensive analysis per job supporting resource per managerial decision area (MDA). When the origin of the information is of interest, Appendix IV can be consulted.

MDA1) Preventive maintenance – job level

a. *Spares, tools and external services*: availability before due date (date of order, expected & actual delivery date)
b. *Facilities*: minimum vessel status job & actual vessel status job
c. *Time*: occurrence maintenance opportunities (start, expected duration, end)
d. *Per preventive maintenance job*: begin & due date, start & finish date. Delays might trigger an improvement project to the planning.

MDA2) Preventive maintenance – resource level

a. Aggregated information per job supporting resource: costs, delays
b. Downtime due to planned maintenance and insufficient maintenance opportunities

MDA3) Corrective maintenance – job level

a. Per stage (diagnosing, preparing, executing, returning) of the repair job: duration

MDA4) Corrective maintenance – resource level

a. Aggregate information per job supporting resource per vessel status: costs, duration preparations

MDA5) Maintenance plan corrective and preventive maintenance – equipment level

a. Information of jobs per equipment: costs.
b. Information per effect on condition for all jobs.
c. Total critical failures: total downtime, total time of preparations

5.4 Input & output DST

So far, FMS' information per job supporting resource is identified. This section discusses input data, necessary calculations and output performance indicators.

5.4.1 Input - Data

The information of the previous Section 5.3 is used to create a list of data per job supporting resource. Appendix V contains the full list of data used for the DST.

Per spare part, tool and external service the following data is required:

- Date of order, planned delivery and actual delivery
- Costs
- Maintenance job

Per maintenance opportunity the following data is required:

- Expected start and end time
- Actual start and end time
- Type of maintenance opportunity
- [When dedicated for maintenance] Costs facilities

Per crew moment spent on maintenance the following data is required:

- Crew member
- Start and end date of carrying out maintenance
- Maintenance job

Per job the following data is required:

- Per job the time window (earliest start date and due date)

- [When failure related] Time of failure
- [When failure related] Time of diagnosis
- [When failure related] Criticality failure
- The actual start and finish time job
- The starting and finishing condition of equipment
- [When critical failure related] Time return to commercial schedule
- The minimum and actual vessel status
- Involvement spare parts, tools, crew and external services

The data so far are maintenance job or maintenance opportunity related. As mentioned before there are maintenance costs not directly related to maintenance jobs:

- Inventory costs
- Downtime costs per time unit
- Maintenance crew costs

5.4.2 Availability data

The decision support tool (DST) is constructed to support the value of job, resource and equipment level optimisation projects. Appendix V 'Data FMS' shows that 19 of 70 specific pieces of data are currently not stored. E.g. the lacking storage of the due date prevents any analyses of the preventive maintenance schedule, required for preventive maintenance evaluation. The consequence is that there is *no analysis possible*. All data is required to carry out the analysis

The 51 pieces of data that are collected cannot be converted into Excel spreadsheets.

- Workable involves structured information on the availability and usage per job supporting resource

- The job supporting resource information needs to contain a link to a maintenance job

5.4.3 Calculations

The calculations consist of comparisons of the data on time per job, and summations of data of relevant costs. All calculations are explained in Appendix VI 'Calculations'. The calculations are programmed in Excel Visual Basic. A general impression of the calculations:

- Per job all performance values concerning the time and costs are calculated and stored. This enables an overview of the jobs sorted on total costs, delays, bottlenecks and other information of interest.
- The job values are used to calculate total costs per job supporting resource,
- The prioritisation of improvement projects is supported by sorting values of tables manually

5.4.4 Output – Performance indicators

Based on this chapter the general performance indicators that are provided in Section 4.7 are updated. Figure 9 shows the required MPIs.

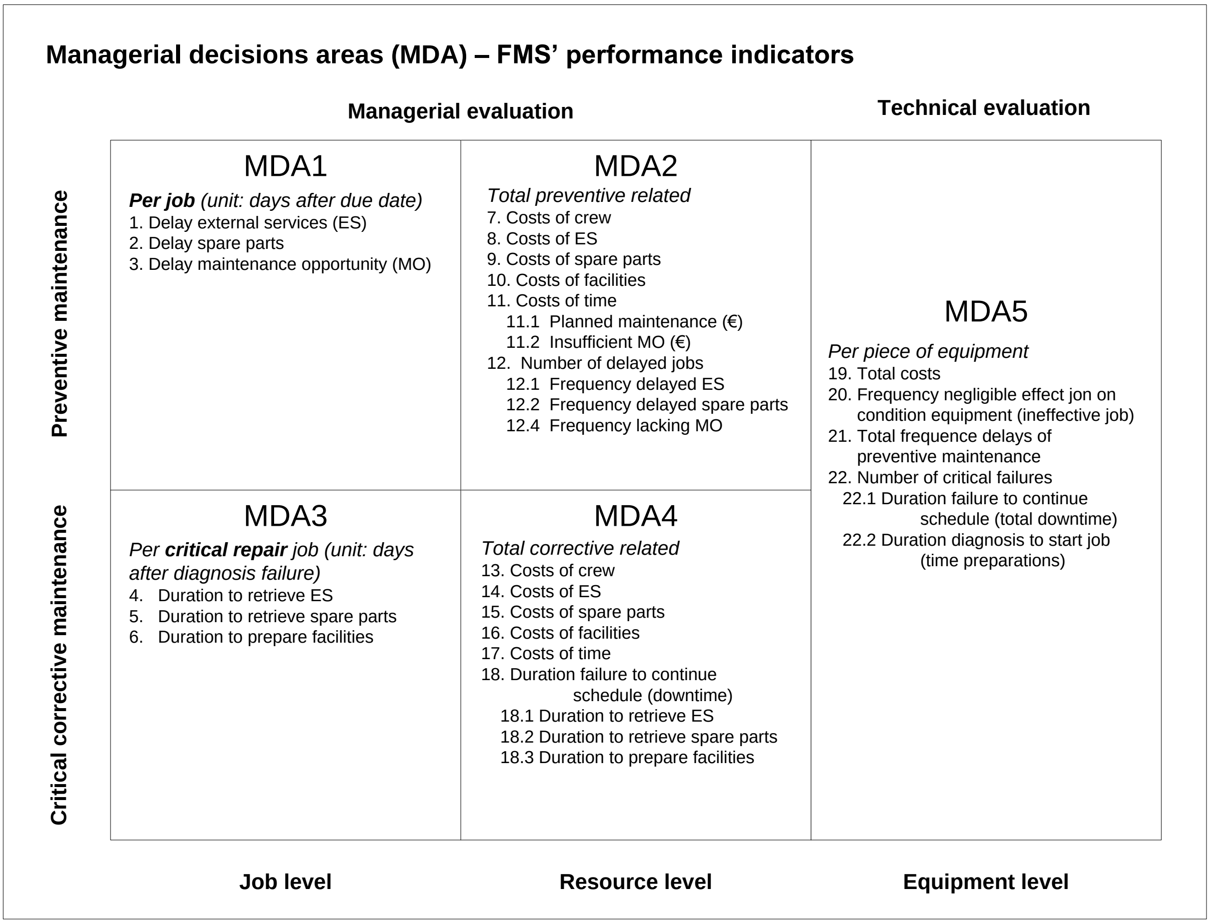

Figure 9 FMS' maintenance performance indicators per managerial decision area

FMS' specific changes compared to the original set of MPIs are:

- Technical documentation and tools are not arranged separately and therefore not measured for MDA1, MDA2, MDA3 and MDA4.
- The delay of facilities is related to the maintenance opportunities at FMS. Therefore the delay of facilities is not separately measured for MDA1.
- Trained personnel are split into crew and external services. The crew is always aboard. Therefore it is not displayed at the delays and durations of MDA1, MDA2, MDA3 and MDA4.
- The costs of time for preventive maintenance are divided into a planned (dry docking periods) and an unplanned (lacking maintenance opportunities) part at MDA2.

5.5 Prioritising the maintenance improvements

Section 4.4 revealed that improvements are required when there are effectiveness and efficiency gaps. Gaps include lacking realisation of the maintenance plan and sub-optimal maintenance organisation.

Improvements on the job level involve the preparation of particular job supporting resources. Details like costs, space and delivery times of job supporting resources determine the optimal settings. When high costs are involved (e.g. downtime due to delivery time) evaluation of current settings is recommended.

Resource level and equipment level optimisation require maintenance engineering concepts (as introduced in Chapter 4.2). The costs involved do not indicate whether something is optimal, but indicate the importance of applying a maintenance engineering concept. The quality of the maintenance engineering concept is not integrated in the DST. The maintenance evaluation should be supported by an overview of applied concepts. The MPM results provide the overview of costs. The evaluation accounts for the current quality of applied ME concepts in order to estimate the profitability of an improvement.

The initial organisation of maintenance by applying ME concepts relies on suppliers' recommendations. An overview of the magnitude of data requirements to in-house improve the organisation is given per MDA and visualised in Figure 10:

1) Least data is involved with job level improvements. The optimisation concerns the availability of individual job supporting resources for corrective and preventive maintenance. The downtime costs of critical failures can be significant (MDA3).

2) Optimising the organisation of job supporting resources for preventive maintenance requires an overview of all required job supporting resources.

3) Improving the organisation of corrective maintenance requires modelling of failures, requiring a significant amount of data.

4) Optimisation of the current maintenance strategy of a piece of equipment requires modelling of deterioration and costs estimations for different maintenance strategies. A lot of data is required to do in-house maintenance strategy optimisation. Technological innovation in the market should be monitored for improving maintenance of expensive equipment.

The colours green – orange – red – dark red are associated with a progressive need of data of in-house optimisation.

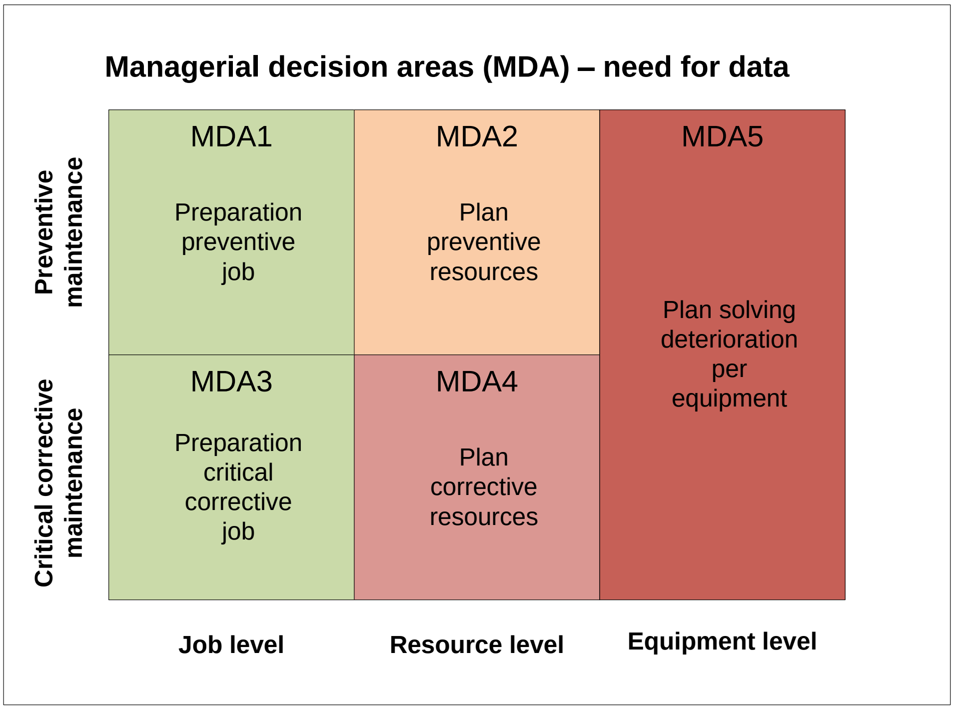

Figure 10 Difficulty per managerial decision area – data related

Expected improvements:

- Job level improvements can be initiated when MPM results points out unavailable job supporting resources.

- Improving preparations on the resource level is not expected to happen often when suppliers' recommendations are already integrated in applying maintenance engineering concepts.

- Technological innovations are expected to have more impact on improved maintenance plans than in-house simulations with gathered data, because a lot of data is required for reliable simulations.

5.6 Conclusions

The MPIs and corresponding data entries to support FMS' maintenance evaluation are identified. The overview, including missing data entries, is listed in Appendix V.

First requirement of equipment level maintenance plan improvements is achieving the maintenance plan. Job level data on job supporting resources reveal the quality of preparations. Finish and due dates of maintenance jobs show the current achievement of the maintenance plan. The same applies to resource level improvements: the current resource plan needs to be carried out.

The job level effect on the maintenance performance is measured, i.e. the downtime and costs related to the job is made visible in the DST.

The data gathering possibilities at FMS are limited due to the limited similarity of vessels and equipment aboard. The maintenance plan is recommended by the supplier. While data is not supporting reliable models of failure behaviour, the best FMS can do is applying the maintenance engineering concept on suppliers' recommended maintenance plan. After the initial optimisation of the organisation of resources, FMS can focus on job level improvements. All usage of job supporting resources is required for the comprehensive overview of cost drivers.

1) *Job level*: preparing the job supporting resources to minimise delays and downtime is of highest priority to ensure optimal maintenance performance
2) *Resource level*: when the organisation of resources are optimised given the suppliers' recommended maintenance plan, resource level improvements are limited
3) *Equipment level*: modelling deterioration reliably and improving the maintenance plan accordingly requires a lot of data. The fleet of FMS is limited, so modelling possibilities are limited.

The required and available data is identified. The DST requires 70 different data entries, of which 51 are currently gathered. The lacking data include among others:

- the due date per preventive maintenance job
- the condition at the start and finishing of the job
- the start and finish date of the job
- the crew hours involved with the jobs
- the time of failure

Alone, the lack of these data prevents us to do a performance measurement on a set of FMS' data. E.g. time related data is required for all improvements. Moreover, 'Star' currently does not have the functionality to provide useful cost data per job in a spreadsheet.

Reliability analyses and corresponding risk estimations are expected to be limited due to data availability. Suppliers' recommendations are the primary source of information. The best FMS can do is evaluate maintenance supported by a clear overview of costs, delays and downtime per maintenance job. Monitoring and controlling the availability of job supporting resources is the key to achieve the maintenance plan. The following chapter shows the distribution of costs, delays and downtime per maintenance job.

6 Result – Performance measures for decision making

The DST provides the MPM results to evaluate maintenance for the purposes identified in Section 2.3. Optimal maintenance organisation has optimised the decision making at the equipment level, resource level and job level in order to minimise the expected costs of deterioration. Maintenance engineering (ME) concepts have to be applied to optimise performance. When the ME concepts are carried out based on suppliers' recommended maintenance plan, the primary objective is to carry out the maintenance plan. It is not possible to evaluate the achievement of the maintenance plan, because data is lacking as discussed in Section 5.4. This prevents us to carry out a performance measurement based on real data. A dummy dataset based on the characteristics of FMS job supporting resources is constructed. The goal is to provide a comprehensive overview of maintenance costs, based on job level information to be able to identify the performance driving jobs. The magnitude of costs per job supporting resource is based on the baseline study, shown in Appendix II.

Section 6.1 shows an overview of the distribution of costs. Section 6.2 shows the MPM results per managerial decision area. Section 6.3 is about the validation of the MPM tool according to the ten identified MPM basics of Section 4.6. The comprehensiveness of MPM approach has been approved by the maintenance experts at FMS at an earlier stage. The implementation of the approved MPM approach is the primary objective. Section 6.4 is about the verification of the MPM tool. Section 6.5 introduces the plan of implementation at FMS. Section 6.6 provides the conclusions of this chapter.

6.1 Introduction & overview distribution of costs

The DST is built to support all managerial maintenance decisions according to the MPM approach. The dataset, shown in Appendix VII, contains 55, including 7 non-critical failures, preventive maintenance jobs and 7 critical corrective jobs. The baseline study (Appendix II) is consulted to approximate the total costs of inventory of spare parts and tools, downtime (missed revenues) and crew, and the duration of dry docking periods. These costs are not linked to particular maintenance jobs. These costs are manually put in the decision support tool, as shown in Table 2.

Vessel	Dummy Vessel
Downtime costs / day	€ 50,000
Average value critical stock	€ 500,000
Average value preventive stock	€ 10,000
Costs of stock	15%
Costs of maintenance crew	€ 200,000
Percentage preventive	75%

Table 2 Non-job related costs, manual input spreadsheet

The input of Table 2 is required in addition to the 70 data entries of the maintenance jobs listed in Appendix V.

Figure 11 on the following page provides an overview of the distribution of costs of the 'Dummy Vessel'. The downtime costs turn out to be the largest cost driver of our dummy dataset. Reducing the missed revenues is of primary interest of FMS. Experiences on the job level need to be translated to improved maintenance preparations.

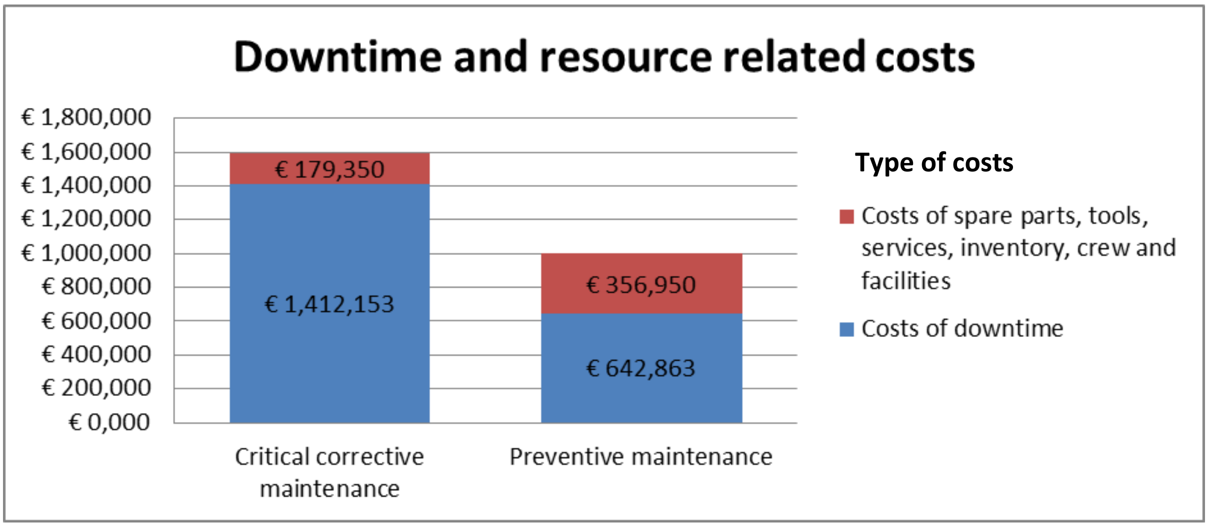

Figure 11 Overview costs per vessel per period of assessed maintenance jobs

The total maintenance costs of the dummy vessel are €2,591,316. The highest costs are involved with the downtime of critical corrective maintenance, so the highest priority is to reduce downtime at the 'Dummy Vessel'. As mentioned in Section 5.6, least effort is involved with the job level improvements, so the critical repair preparations are (MDA3) of highest interest.

The costs of preventive maintenance downtime' are also significant. Section 5.3 has pointed out that preventive maintenance related missed revenues could be caused by planned maintenance and insufficient maintenance opportunities. Improvements at the job level related to exploiting maintenance opportunities are of interest (MDA1). Dry docking maintenance is also utilising the vessel. Dry docking preparations and planning are worth optimising (MDA2).

6.2 Performance indicators per managerial decision

The MPIs of the managerial decision areas are shown and discussed starting at MDA1 to MDA5 in the following subsections. The MPIs have been shown in Section 5.4.4.

6.2.1 MDA1) Preventive maintenance – job level

At FMS the performance indicators include the delay of external services, spare parts and maintenance opportunities. When a maintenance job is overdue, it could be caused by missing one of the job supporting resources to finish the job before the due date. The job cause of the delay needs to be revealed: e.g. a late order or a late delivery. When the MPM results do not identify a missing resource at the due date, the Chief Engineer needs to be consulted to check what has caused the delay.

Table 3 shows the lacking preparations of resources for the delayed jobs.

Job ID	Minimum vessel status	Due date	Finishing time & date	Waiting time spare parts	Waiting time external	Start latest MO before due date
PFSSV0004	Alongside	1-2-2013	20-2-2013 17:29		18.3	23-1-2013 8:00
PFSSV0005	Sailing	1-3-2013	3-3-2013 21:44			
PFSSV0012	Alongside	1-3-2013	2-3-2013 10:04			1-3-2013 20:00
PFSSV0024	Anchoring	1-4-2013	15-4-2013 8:38			20-3-2013 8:00
PFSSV0033	Anchoring	1-6-2013	2-6-2013 10:48			1-6-2013 15:35
PFSSV0035	Anchoring	1-6-2013	3-6-2013 2:25			1-6-2013 15:35
PFSSV0037	Alongside	1-6-2013	13-6-2013 12:50			Lacking opportunity
PFSSV0038	Alongside	1-10-2013	8-11-2013 2:52	28.3		1-10-2013 12:00
PFSSV0039	Operation	1-7-2013	6-7-2013 2:16			
PFSSV0040	Operation	1-7-2013	7-7-2013 12:50			
PFSSV0041	Operation	1-7-2013	5-7-2013 0:03			
PFSSV0046	Sailing	1-8-2013	5-8-2013 9:23			
PFSSV0047	Anchoring	1-8-2013	7-8-2013 16:10			Lacking opportunity
PFSSV0048	Sailing	1-12-2013	7-12-2013 6:43			
PFSSV0050	Anchoring	1-12-2013	9-12-2013 18:45			27-11-2013 8:00

Table 3 Bottleneck analysis delayed jobs

The analysis identifies one late spare part (28.3 days) and one late appointment (18.3 days) with an external service engineer. The improvement project requires checking the order date and expected delivery date.

The jobs with a sailing or operation minimum vessel status did not have any lacking job supporting resources. In this dummy case, the chief engineer in charge could be consulted to figure out what was the cause of delay. The date of the latest MO is not calculated for this type of jobs as we expect that there would be plenty time to carry out the job.

The ‘lacking opportunity’ status means that the latest maintenance opportunity started before 2 weeks of the deadline.

In reality, the difference between the latest MO and the finishing time & date indicate how the chief engineer uses of the schedule. Analysis reveals when he is working in advance when a maintenance opportunity occurs, or that he starts working when the job is overdue.

6.2.2 MDA2) Preventive maintenance – resource level

The performance indicators include the costs per job supporting resource and the frequency of delayed external services, spare parts and maintenance opportunities (MOs). Table 3 (above) shows that the frequency of delays is only one per resource. The organisation is good. Figure 12 shows the total costs of the preventive job supporting resources.

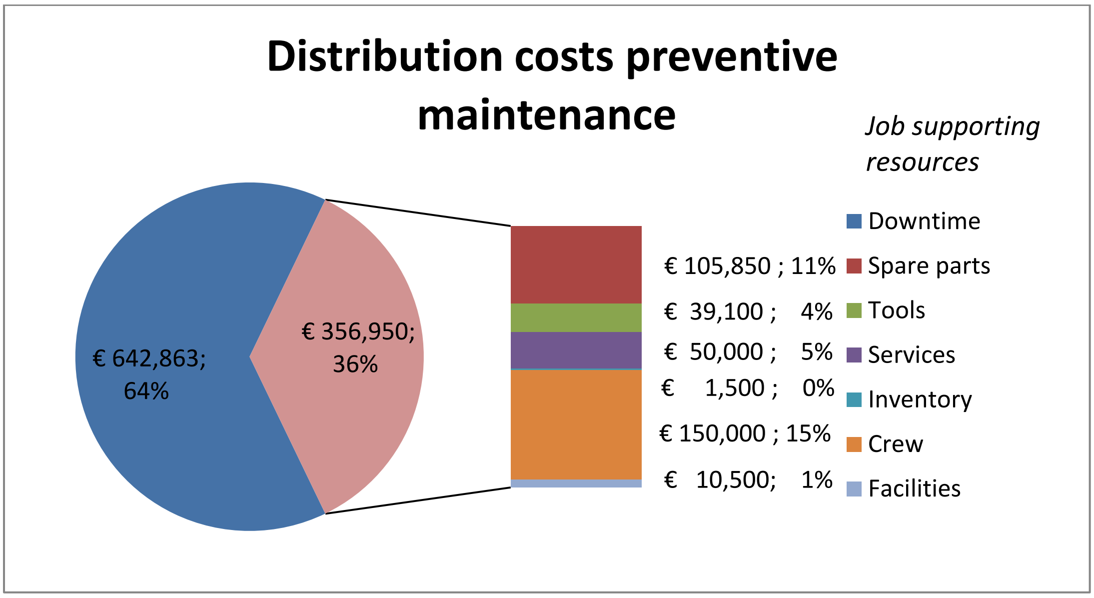

Figure 12 Distribution costs preventive maintenance

The highest costs are involved with the costs of downtime. The following figure, Figure 13, provides the time related performance indicators 'Planned maintenance' and 'Insufficient MO'.

The second largest cost is the cost of crew. Optimising the crew costs requires an extensive assessment of competences and capacity requirements, including non-maintenance related activities. Moreover, the costs of outsourcing need to be integrated in the decision.

The usage costs are directly linked to the maintenance plan. Significantly decreasing these costs requires changes of the equipment's maintenance plans (MDA5). In addition, some purchase discounts might be possible, but this is not of primary interest.

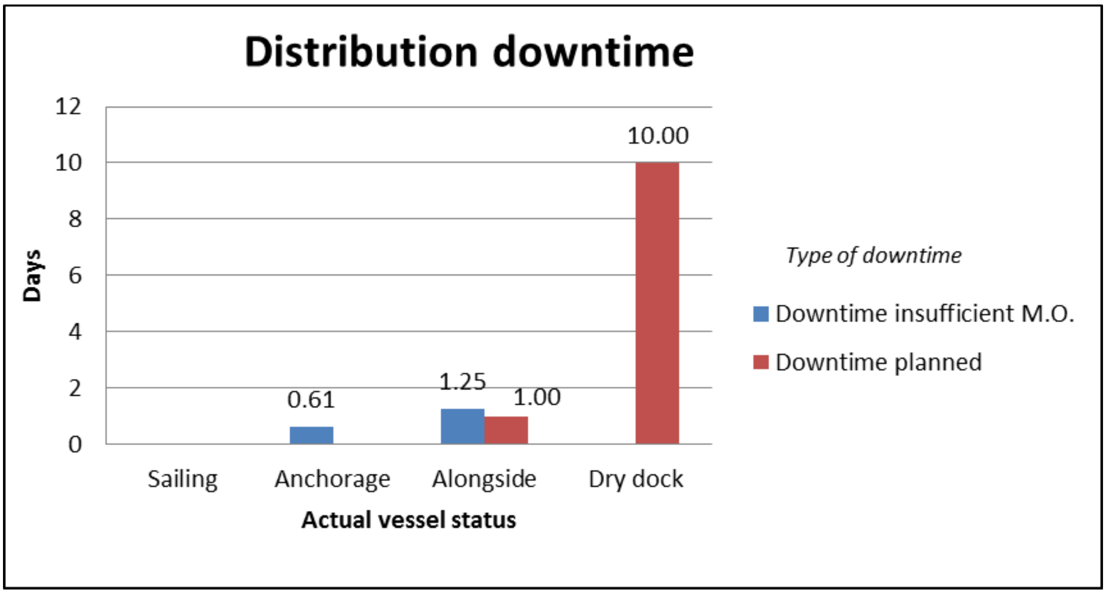

Figure 13 Overview distribution days of downtime

Figure 13 shows that the largest part of downtime is caused by the planned dry docking period. One should plan the period during a season with much expected bad weather to reduce the missed revenues. The importance of lean and proper organisation of these dry docking periods is important to minimise the missed revenues (resource level improvement project towards dry docking periods). Decreasing the total time at the dry dock is worth the day rate of a vessel per day saved. The day rate of a FSSV is on average €50,000.

The downtime caused by insufficient MOs harms FMS' reputation. Exploration of the downtime causing jobs (available by filtering in Excel) in the tool could shows whether it is related to a job supporting resource. E.g. the maintenance opportunity could have been shorter than predicted.

6.2.3 **MDA3) Corrective maintenance – job level**

FMS' performance indicators are the duration to retrieve external services, spare parts and facilities. Corrective maintenance is involved with nearly €1.6 million, of which the costs of downtime are accountable for €1.4 million. With a day rate of €50,000 approximately the vessel has been unavailable for 28 days. Figure 14 shows the distribution of downtime.

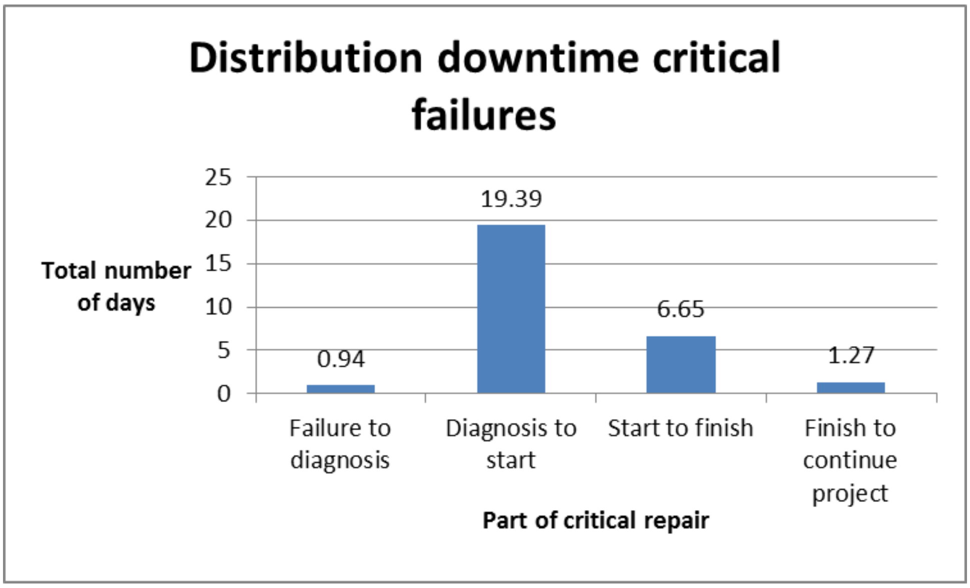

Figure 14 Distribution of downtime critical failures

The duration of the diagnosis determines the time for maintenance job preparations. The minimum vessel status determines the minimum time of preparations. The vessel needs to achieve the right status before the job can be carried out. Changing the minimum vessel status requires a change of design, which is not the maintenance manager's decision. Table 4 shows the delays of the supporting resources.

Job ID	Total downtime	Minimum stance vessel	Resulting stance vessel	Time diagnosis to start job	Preparation time vessel	Waiting time spare part	Waiting time tool	Waiting time external service
CFSSV0001	1.43	Sailing	Anchoring	1.04	0.25	1.04	0.00	0.00
CFSSV0002	1.70	Sailing	Sailing	0.00	0.00	0.00	0.00	0.00
CFSSV0003	1.87	Anchoring	Anchoring	0.52	0.23	0.00	0.00	0.50
CFSSV0004	3.54	Sailing	Anchoring	2.82	0.16	0.00	2.86	2.84
CFSSV0005	0.14	Sailing	Sailing	0.00	0.00	0.00	0.00	0.00
CFSSV0006	5.31	Anchoring	Anchoring	2.01	2.00	0.00	2.97	2.93
CFSSV0007	14.25	Anchoring	Anchoring	12.99	0.99	14.03	0.00	0.00

Table 4 Bottleneck analysis job supporting resources, critical repairs

The 'Time diagnosis to start job' is the total time of the preparations. The repair can be started before all required supporting resources are aboard. Nevertheless, all resources are required to finish the job.

The future immediate availability of a bottleneck resource reduces the waiting time only to a limited extent. Namely, the waiting time of the follow-up bottleneck is still there. Besides, the decision to put the spare part aboard also *depends on the likeliness* that the failure happens again. An example:

Consider that a similar failure as CFSSV0007, shown in Table 4 happens again in the future. CFSSV0007 the 'diagnosis to start job' duration was 12.99 days and the preparation time of the vessel, the follow-up bottleneck, is 0.99 days. This time, the spare part is immediately available. When the lead time is similar, which makes the value of the availability of the spare part equal to a reduction of 12 days missed revenues: 12 * €50,000 = €600,000.

6.2.4 **MDA4) Corrective maintenance – resource level**

The performance indicators include the total costs per job supporting resource and the duration to retrieve the external services, spare parts and facilities. The downtime related to critical failures is significant. However, the number of critical failures is limited, so a quick glance at Table 4 (previous page) reveals whether one of the resources is structurally long. A bottleneck analyses shows the interest of revealing the need of a resource policy improvement.

Figure 15 shows the costs per job supporting resource involved with critical repairs.

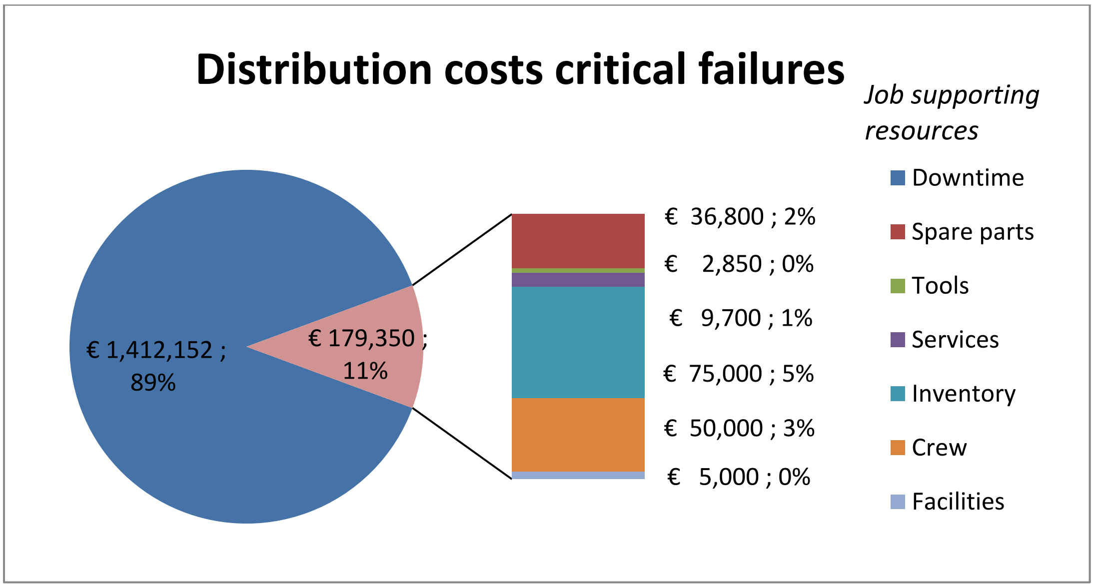

Figure 15 Distribution costs critical failures

The 89% of costs, downtime, have already been discussed at the job level (MDA3). The 3% crew costs (€50,000) can be influenced by the crew capacity optimisation, integrated with the capacity and competences required for preventive maintenance.

Another challenge is the organisation of inventory. Although the 15% costs (Table 2, page 38) per € per year might be higher, the total costs are limited. Let's assume that the maximum would be 30%, which is €150,000 per year. That would be the equivalent of 3 days of missed revenues, assuming €50,000 revenues per day. Minimising the value of inventory is not really interesting. Instead, *reducing lead time by availability on board* or *close collaboration with suppliers* in cases of critical breakdowns is of interest.

As lead times of tools and spare parts could be really high, the inventory project deserves attention. Nevertheless the possibilities of modelling failure behaviour are limited. The initial selection of spare parts is made based on suppliers' recommendations, available space aboard and minimum vessel status per repair. Gathering sufficient data to predict failure behaviour in-house and adjust the selection of spare parts and tools accordingly might be beyond the possibilities. The quickest way to improve future behaviour is to check individual parts that were not available (MDA3).

When a particular supporting resource is often a bottleneck, it is an indication that the organisation of the resource needs to be reassessed. The number of times a job supporting resource is a bottleneck overview of the bottleneck preparations is given in Figure 16.

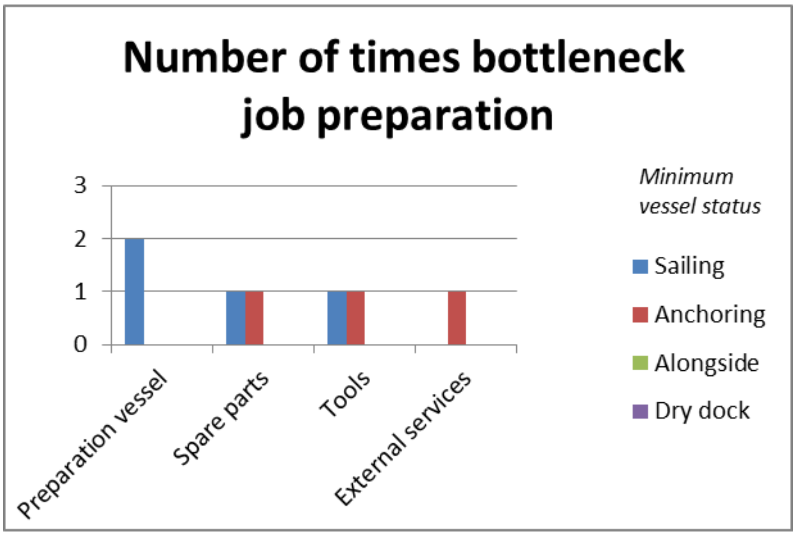

Figure 16 Overview quantity bottleneck per job supporting resource

The minimum vessel status is related to the vessel design. Therefore, when “Preparation vessel” is the bottleneck, the preparations cannot be improved to reduce downtime.

When a ‘sailing’ job lacks a spare part or tool, the vessel needs a helicopter delivery or a port visit to get the job resource aboard. When the job resource would be available immediately, the repair could be conducted immediately, assumed that the crew is capable of carrying out the job. Then the time required to sail to a port is saved. The result is that the value of available spare parts and tools for sailing jobs is highest.

6.2.5 **MDA5) Maintenance plan – equipment level**

The performance indicators include the total costs, the frequency of negligible effect on the equipment’s condition, the delayed jobs, the potential downtime involved and the time of preparations.

All equipment has a maintenance plan to deal with its expected deterioration. Improving the maintenance plan per piece of equipment is a challenging task, which needs a lot of data to model deterioration under different maintenance strategies.

An alternative approach can be applied to decrease the costs by improving the maintenance schedule. When the costs of equipment consist of direct preventive maintenance costs (or crew hours, which are currently not measured), while the effect on condition is negligible, the interval between maintenance jobs could be extended to reduce the costs. The required indicators for MD5 are shown in Table 5. For example, a piece of equipment fitting the conditions for the alternative approach is equipment E0126 with €17,000.

Equipment ID	Number of Jobs	Number of repair jobs	Number of overdue jobs	Total costs	Total direct costs	Total downtime costs	Downtime unavailable job supporting resources (days)	Number of ineffective jobs
E1000	1	1	0	€ 717,465	€ 5,000	€ 712,465	12.99	0
E0003	3	1	1	€ 287,775	€ 22,150	€ 265,625	2.01	2
E0004	4	2	2	€ 238,063	€ 37,550	€ 200,513	2.82	1
E0001	5	2	1	€ 184,731	€ 19,800	€ 164,931	1.56	2
E0002	4	1	2	€ 107,496	€ 22,600	€ 84,896	0.00	2
E0083	1	0	1	€ 40,542	€ 1,300	€ 39,242	0.00	0
E0089	2	2	1	€ 29,500	€ 29,500	€ -	0.00	2
E0007	4	0	0	€ 29,480	€ 3,350	€ 26,130	0.00	3
E0028	2	0	0	€ 18,500	€ 18,500	€ -	0.00	0
E0126	1	0	1	€ 17,000	€ 17,000	€ -	0.00	1
E0079	1	0	1	€ 11,000	€ 11,000	€ -	0.00	0
E0087	1	1	0	€ 9,153	€ 2,000	€ 7,153	0.00	0
E0076	2	0	0	€ 7,900	€ 7,900	€ -	0.00	1
E0082	1	0	0	€ 6,150	€ 6,150	€ -	0.00	0
E0123	1	0	0	€ 6,100	€ 6,100	€ -	0.00	0
E0075	2	0	0	€ 5,700	€ 5,700	€ -	0.00	0
E0100	1	1	0	€ 5,657	€ 2,600	€ 3,057	0.00	0
E0078	1	0	0	€ 4,405	€ 3,400	€ 1,005	0.00	0
E0006	2	0	0	€ 2,700	€ 2,700	€ -	0.00	1
E9810	1	0	0	€ 2,000	€ 2,000	€ -	0.00	0
E0077	1	0	0	€ 1,900	€ 1,900	€ -	0.00	0
E0509	1	1	0	€ 1,800	€ 1,800	€ -	0.00	0
E0010	1	0	0	€ 1,700	€ 1,700	€ -	0.00	0
E0074	2	0	0	€ 1,700	€ 1,700	€ -	0.00	0
E0124	1	0	0	€ 1,400	€ 1,400	€ -	0.00	0
E0128	1	0	0	€ 1,300	€ 1,300	€ -	0.00	0
E0008	1	0	1	€ 1,200	€ 1,200	€ -	0.00	1
E0050	1	1	1	€ 1,200	€ 1,200	€ -	0.00	1
E0005	3	0	1	€ 1,100	€ 1,100	€ -	0.00	0
E0080	1	0	0	€ 1,000	€ 1,000	€ -	0.00	0
E0130	1	0	0	€ 1,000	€ 1,000	€ -	0.00	0
E0073	1	0	0	€ 600	€ 600	€ -	0.00	0
E0009	1	0	0	€ 500	€ 500	€ -	0.00	0
E0125	1	0	0	€ 500	€ 500	€ -	0.00	0
E0127	1	0	0	€ 500	€ 500	€ -	0.00	0
E0129	1	0	0	€ 500	€ 500	€ -	0.00	0
E0081	1	0	1	€ 100	€ 100	€ -	0.00	0
E1001	1	1	1	€ -	€ -	€ -	0.00	0
E1100	1	0	0	€ -	€ -	€ -	0.00	0
Total	62	14	15	€ 1,749,316	€ 244,300	€ 1,505,016	19.39	17

Table 5 Overview total costs involved per maintenance job sorted per piece of equipment

The high costs are primarily related to downtime costs; this has already been stated in the previous sections. As concluded in Section 5.6, improvements of the maintenance plan are more likely to succeed when technological improvements become available, than the in-house modelling of data using data on maintenance jobs.

When comparing the total costs of the tables, the costs that are not allocated to jobs need to be accounted for. These costs include the costs of crew (€200,000) and inventory (€75,000 +

€1,500), costs of facilities (€15,500) and downtime of planned maintenance (€550,000). The total non-allocated costs are €842,000. Summed with the total of Table 5, €1,749,316, makes €2,591,316. This is equal to the total costs mentioned in Section 5.1.

6.2.6 **Conclusions**

This section has shown the MPM results. The maintenance evaluation with the purpose to initiate maintenance improvements requires assessing the current level of the policy involved. Details on purposes of maintenance evaluation are shown in Section 2.3.

Spare parts and tools are currently no improvement opportunity at FMS as there has already been executed a project to set up the basics of spare part and inventory management. As the crew and the dry docking periods are involved with high costs and the efforts to optimise the organisation have been limited, we recommend initiating improvement projects.

Based on the comprehensive overview of costs and related level of FMS' maintenance organisation, the recommended maintenance improvement projects are:

1) An improvement project towards the organisation of dry docking periods can be started. Planned dry docking periods last generally 7 days or longer. Optimal planning of the maintenance and execution period is of high interest. Currently, there is no feedback system to learn from the dry docking experiences.
    a. Additional €50,000 revenues per extra day of commercial projects.
2) Optimise the procedure to select the crew. It is of importance to fit the in- & outsource decision with the crew capabilities and capacities aboard. This improvement requires information on the required capacities.
    a. Yearly crew costs approximately €1,000,000; majority of the crew is, although not necessarily fulltime, involved with maintenance. Improvement potential is unknown as it is unknown what time all the different tasks take.
3) Learn from the unexpected critical failures. Assess the value to put aboard a lacking job supporting resource for a similar critical failure in the future. This also depends on the probability the failure happens again.
    a. Lead times of job supporting resources cause missed revenues of €50,000 per day of downtime of a FSSV.

6.3 Validation

Validation is concerned with model correctness with the system under study (Altiok & Melamed, 2007, P141). The research MPM approach is rooted in the definition of optimal maintenance (see Section 4.6). The MPM approach is approved by the FMS' maintenance experts. The MPM results identify the performance driving costs, job supporting resources and equipment. The costs, delays and downtime can be sorted using the Excel tables. Follow up improvements depend on the evaluation of causes of delays and downtime. FMS' maintenance experts are aware off the necessity of proper registration to reveal the causes of delays. The remaining challenge is to minimise the effort to align 'Star' output with the DST input. FMS' maintenance experts are aware off the possible consequences when the alignment is lacking. Important is the validation according to the ten basics of the MPM approach, identified in Section 4.6.

The decision support tool does not require simulations. The spreadsheet model uses data of the maintenance jobs. The data is used to identify the actual costs involved with the maintenance job supporting resources. Therefore checks of the results with reality are not of interest. The validation of the MPM results concerns the alignment with the definition of the optimal maintenance organisation. The maintenance organisation is optimal when the expected costs of deterioration are minimised given the information available.

We check to what extent the resulting decision based performance measurement tool fits the ten basics:

1) Maintenance optimisation is in principle an activity concerning the gathering and analysing of data at the component level to optimise the maintenance schedule.

Per job supporting resource is indicated whether it could be improved on a job level or a resource policy level. For both corrective and preventive maintenance the feedback is generated to support the managerial analysis as well as the technical analysis to optimise the maintenance schedule.

2) Assess impact (savings) of improvement project versus the efforts (costs) required.

The potential savings are indicated on a job supporting resource level per job. The savings and efforts of optimising general maintenance policies require further analyses; the total costs per resource are calculated, which offers the prioritisation of further analyses.

3) Maintenance evaluation assesses decisions of system's design, maintenance strategy selection and maintenance task control in three feedback loops to identify maintenance improvement areas.

The decision support tool provides feedback to the three areas of decision making, direct or indirect. First, the feedback to the maintenance task control is provided on a job level per job supporting resource. The assessment of the policy is limited to an indication of lacking resources (including downtime) as well as the costs involved. Whether the policy can be improved, requires further analysis. Second, the feedback to the maintenance strategy selection is provided by a detailed overview of all jobs per type of equipment: the overview supports the decision whether the maintenance strategy and associated plan of the job is worth a closer assessment. Third, the feedback to system's design is indirect: when effectiveness and efficiency improvement projects are not satisfying, the design needs to be improved.

4) Effectiveness of maintenance jobs depends on the effect on the condition of the equipment.

We have implemented a three point scale of condition of equipment: bad, moderate, good. This classification gives a general impression whether maintenance is effective. However, improving effectiveness needs more details. We recommend limiting the effort to identify these details to the cost driving equipment, given that in-house technical optimisation of maintenance plans fit the ambitions of FMS.

5) Efficiency of maintenance depends on the total minimum costs of maintenance.

The total minimum costs of maintenance are not estimated. However, assuming that the current maintenance plan is the best decision given available information, the preventive bottleneck delays and critical repair downtime costs show the gap of current situation with the optimal situation. The optimum of costs of general organisation of job supporting resources requires further analyses.

6) Maintenance performance evaluation consists of a technical and a managerial component.

Managerial decisions are constructed for the technical and managerial component. The tool supports this decision making.

7) The managerial evaluation includes the achievement of the maintenance plan and the distribution of costs over the job supporting resources.

The preventive part is assessed with an overdue job and bottleneck analysis. The information of available job supporting resources aboard to cope with critical repairs is not implemented in the tool. Nevertheless, lacking job supporting resources are identified.

8) The technical evaluation includes the effectiveness to deal with deterioration and the costs involved.

The decision support tool provides an overview of all jobs with costs and indication of effect on equipment. The evaluation is supported.

9) Changing the system design is an expensive possibility when optimal maintenance strategy planning and maintenance task control are not satisfying.

The tool does not indicate whether a part of the system is insufficient. However, the tool provides an overview of all costs involved per piece of equipment to support the decision maker assessing whether a design improvement is required.

10) Total maintenance costs consist of job supporting resources, namely trained personnel, spare parts, facilities, technical documentation, tools and time.

The details of FMS vessel management circumstances are applied to the indicated job supporting resources. FMS requires the supplier to supply the technical documentation at the purchase of equipment. The costs of technical documentation are left out of the scope. The tool calculates all costs involved with FMS' job supporting resources.

6.3.1 **Conclusions**

The MPM tool is valid based on the assessment of the ten basics of performance measurement according to maintenance evaluation literature. Maintenance performance is about dealing with deterioration effectively and efficiently. Optimality depends on the available information to optimise decision making.

The requirement to enable an assessment of effectiveness is a proper execution of the maintenance plan: the delays of the preventive jobs are calculated. When the maintenance plan is carried out properly, the effect on the condition of equipment is limited and/ or the costs are considered as too high, an improvement project to the maintenance plan of the equipment is supported by data on the carried out jobs.

Efficiency depends on the current total costs compared to the minimum total costs. Optimality problem solving of job supporting resource policies and maintenance strategy selection per equipment is supported by job level information. The jobs and job supporting resource policies of interest are indicated by the total costs involved. The storage of relevant information per job can be used to sort and find the jobs of interest to improve efficiency.

6.4 Verification

Verification assesses whether the tool is constructed according to the intended model (Altiok & Melamed, 2007, P141-142). The programming includes comparisons of all component level data and summations of calculated information. Many job details are stored in tables at the spreadsheet. This enables us to check whether aggregated results fit the sum of the individuals. The following checks for inconsistences have been carried out:

- Check on similarity total costs input & output slides per job supporting resource
- Check on output total downtime per type of maintenance & job output
- Check on output overview bottleneck & preventive job output
- Check resulting maintenance opportunity downtime per job and maintenance opportunity

All checks can be carried out using the data sheets and results of Section 6.2. When determining total costs one should be aware that these contain non-job related costs like inventory and crew costs. Also costs of facilities are not allocated to the jobs.

6.5 Implementation plan FMS

The emphasis of the research has been on the development of a MPM approach. The implementation of the MPM methodology requires the conversion of 'Star' to gather all data. The availability of data (19 out of 70 pieces of data is missing) at FMS is shown in Appendix V. The conversion of 'Star' needs to be aligned with the DST:

1) Enabling the registration of all required data entries.
2) Process all data to Excel spreadsheets. The data per job supporting resource needs to be matched with the job.
3) The 'Star' output is unknown. To minimise the efforts of MPM, 'Star' output needs to be aligned with the DST input. When necessary, the DST needs to be adjusted. Close collaboration between M&RE and 'Star' developers is recommended.

An indication of the required trajectory of the conversion of 'Star' is provided and discussed in Appendix VIII. Appendix IX contains a flowchart of who registers what data at what moment. However, this needs to be reassessed when the conversion of 'Star' is finished.

The comprehensive approach has identified all maintenance performance drivers. The evaluation of current level of organisation and the impact on performance has resulted in three maintenance improvements, indicated by Section 6.2.6. The following projects should be carried out by the M&RE department:

1) An improvement project towards the organisation of dry docking periods can be started. Planned dry docking periods last generally 7 days or longer. Optimal planning of the maintenance and execution period is of high interest. Currently, there is no feedback system to learn from the dry docking experiences.
2) Optimise the procedure to select the crew. It is of importance to fit the in- & outsource decision with the crew capabilities and capacities aboard. This improvement requires information on the required capacities.
3) Learn from the unexpected critical failures. Assess the value to put aboard a lacking job supporting resource for a similar critical failure in the future. This also depends on the probability the failure happens again.

6.6 Conclusions

The MPM results are calculated, discussed, validated and verified in this chapter.

The comprehensive maintenance approach of the MPM methodology enables the construction of an overview of all costs to put the costs in perspective. This provides a trustworthy platform to prioritise maintenance improvements. There are no missing maintenance costs, because all costs are taken into account.

Moreover, all job related maintenance costs are linked to the maintenance jobs. This enables the identification of the impact of all job supporting resources involved, the building block of a maintenance job. The DST has stored all data in Excel per maintenance job, which makes it easy to identify the high impact preparations.

Moreover, policy improvement projects are identified and prioritised based on the validated and verified MPM approach. The resource level improvements are based on the evaluation of the MPM results (based on magnitude costs Fugro Standard Survey Vessel, Baseline study Appendix II) and the current level of the resource policies. Figure 17 shows the improvement projects per managerial decision area. Details can be found in Section 6.2.6.

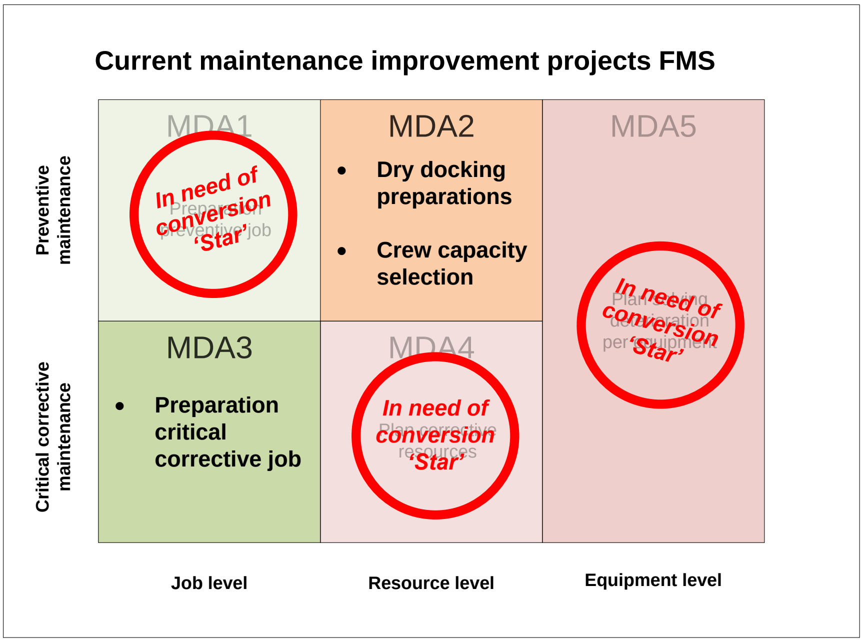

Figure 17 Current improvement projects FMS

7 Conclusions & Recommendations

Section 7.1 provides the conclusions, starting with the main conclusions. Section 7.2 provides recommendations. Section 7.3 discusses future research.

7.1 Conclusions

Maintenance performance measurement (MPM) supports the evaluation of maintenance to assess how to improve performance. Optimal maintenance performance minimises the costs of deterioration given the constraints and the information available. Costs of deterioration include the costs of maintenance and the costs of unavailability (missed revenues).

The research objective:

The objective of the research is to develop and test a MPM approach that indicates and prioritises maintenance improvements in order to maximise the OpCo's profit.

This research has developed an MPM approach that resulted in a comprehensive overview of all managerial possibilities to influence maintenance effectiveness and efficiency. The maintenance improvements are prioritised on the impact on overall performance: costs, including missed revenues due to unavailability of the vessel. The costs, that reduce the OpCo's profit, indicate the need of optimisation. The delays of preparations for maintenance jobs indicate what to improve to achieve carrying out the maintenance plan.

The comprehensive overview provides the basis for the following external and internal functions of maintenance evaluation:

1. Show the quality of maintenance
2. Support the short term alignment of the maintenance plan with budgetary restrictions
3. Prioritise maintenance improvement projects (the comprehensive approach has identified all possible maintenance subjects to improve)
4. Generate feedback on the execution of the maintenance plan

Section 7.2 contains recommendations to develop maintenance evaluation practises, as this research focused on the development of the MPM. The practises concern the interpretation of the MPM results to support the internal and external functions. Further details of the functions are shown at the following sub-conclusions of Question 1 and corresponding Chapter 2.

Question 1) What is the potential usefulness of maintenance performance measurement for FMS?

Currently, FMS does not systematically evaluate maintenance performance. Chapter 2 showed the link of maintenance performance measurement (MPM) with OpCo's profit. MPM supports the evaluation of maintenance to identify possibilities to improve maintenance performance. Maintenance decision making should minimise the expected costs of dealing with the effects of deterioration. Every saving at FMS increases the OpCo's profit as FMS is non-profit. The usability of the comprehensive maintenance approach has external and internal functions:

External usability:

- Estimate the quality of maintenance by showing the level of optimality of decision making to organise maintenance. The comprehensive MPM results provide the overview of vessel level performance drivers down to the building blocks of maintenance jobs: the job supporting resources per job.

- The maintenance plan is supposed to minimise costs on the long term. OpCo's short term budgetary constraints need to be met. Latest MPM results that identify the costs and effectiveness of carried out jobs are available. These can be used to support the maintenance settings with the least (increased) risk on downtime.

Internal usability:

- Generate feedback per job supporting resource per job to improve the future realisation of the maintenance plan.
- Prioritise the comprehensive set of maintenance performance drivers. The transparent overview of costs, delays and downtime can be solved firstly by increased realisation of the maintenance plan. Secondly maintenance engineering concepts can be applied when current organisation of performance drivers is not optimal and required data is available.

Question 2) Why is maintenance performance measurement literature not able to come up with a practical approach?

Chapter 3 showed that extensive literature study carried out in 2011 concluded that MPM literature lacks practical MPM tools (Simões et al., 2011). Since Pintelon & Gelders (1992) recommended aligning maintenance objectives with strategic goals, MPM literature has been primarily aimed on this strategic alignment. Strategic objectives are not linked to the effectiveness and efficiency of dealing with deterioration. The result is that the strategic MPM approach lacks practicality to improve maintenance. A MPM approach that supports minimising the effects of deterioration is developed in this research.

Question 3) What is a comprehensive set of managerial maintenance decisions founded on maintenance engineering literature?

Chapter 4 provides a comprehensive set of managerial decision areas (MDAs). The set covers the possibilities to optimise the maintenance organisation.

Information on job supporting resources reveals the impact on maintenance performance per MDA. Costs, delays and preparations times of job supporting resources are required to evaluate performance. When there are no costs, jobs, job delays or downtime involved, it is not of interest for the maintenance evaluation. The 6 job supporting resources are:

1) Trained personnel
2) Spare parts & repair materials
3) Facilities
4) Technical documentation
5) Tools, support & test equipment
6) Time

The effects of maintenance can be solved by *preventive* and *corrective* maintenance. Maintenance evaluation and corresponding improvements are involved with three levels:

1) *Job level* – availability of necessary job supporting resources is required to finish maintenance jobs. Feedback should be given based on availability of job supporting resources and the achievement of the due date.
2) *Resource level* – the organisation of job supporting resources to achieve the maintenance plan. Maintenance engineering concepts should be applied to optimise the organisation.
3) *Equipment level* – the equipment's maintenance plan prescribes the required job supporting resources per job. Maintenance engineering concepts should be applied to minimise effects of deterioration.

The MPM results can be used to identify the performance (costs, delays, and downtime) driving parts of maintenance. The actual initiation of improvement projects depends on the current level of optimisation. When the organisation is optimal, projects are not beneficial.

The managerial decision areas involve decisions for preventive and corrective maintenance on the job, resource and equipment level. Details per job supporting resource per maintenance job are required to trace the performance driving part. The decision then is to check the possibilities to reduce the impact, starting at the highest impact parts.

Question 4) What data is required to set up the information to support FMS' managerial decision making?

The managerial decision areas and corresponding performance indicators per job supporting resource are generally applicable. In Chapter 5, the MPM approach is applied to FMS. The possibilities of the infrastructure of FMS have been taken into account constructing a comprehensive selection of performance indicators. The result is an overview that requires the least modifications of the information system 'Star', while not losing essential evaluation information on job supporting resources.

FMS requires 70 different data entries, of which 51 are already gathered, but not yet retrievable in a usable format. Moreover, the missing 19 data entries are essential for maintenance evaluation. The functionality is approved by FMS' maintenance experts.

Finishing an improvement project most likely requires additional information, like mathematic modelling, future estimations, technological possibilities, technical (deterioration) expertise or suppliers' characteristics. *It is not expected that the required data for MPM fully supports the implementation of the maintenance engineering concept.* For example, modelling deterioration needs more information than a general indication of effect of the maintenance job on a piece of equipment (which does generally indicate whether maintenance is effective). A project to improve the maintenance plan of a piece of equipment starts identifying required technical information.

Question 5) How to display, interpreted and prioritise the performance indicators to support maintenance improvements?

The decision support tool (DST) provides the MPM results based on the prescribed data. The DST is constructed in Excel. The DST supports maintenance evaluation by providing the distribution of costs, delays and downtime per job, job supporting resource and equipment.

The DST contains all performance drivers at the job, resource and equipment level. Optimisation is only of interest when the impact on performance is considered significant. Significance depends on the total costs involved and the decision maker. Excel perfectly supports sorting tables. High impact (high costs, delays) can easily be found by sorting tables with MPM results.

The job details of the contribution of job supporting resources are linked to overall performance (costs, delays and unavailability). The link enables the decision maker to check whether lacking performance is caused by individual jobs. A resource level improvement project is required when delays or downtime are systematically caused by a certain job supporting resource.

The magnitude of maintenance costs is determined by the maintenance plan. The plan prescribes how to cope with the effects of deterioration per piece of equipment. When maintenance costs are unsatisfying, the largest impact is by finding a more efficient way to deal with deterioration. However, this requires modelling equipment's failure behaviour under different maintenance settings or implementing innovative technology.

7.2 Recommendations

The first 4 recommendations concern the organisation of required data to enable MPM supporting maintenance evaluation. Recommendation 5 to 7 concern the development of maintenance evaluation practices. Recommendation 8 and 9 involve FMS' maintenance improvement projects. Appendix VII contains more details on the implementation plan.

1) 'Star' lacking 19 data entries that are essential for the MPM need to be created in the system. The types of entries are similar to existing data entries.
2) Converting 'Star' data to the decision support tool's (DST) spreadsheet requires programming of data reports. The research delivered an overview of required data (Appendix IV), required calculations (Appendix V) and a first version of the DST (first version, because 'Star' output might require DST changes).
3) The 'Star' developers and DST developer need to collaborate to ensure 'Star' output matches the DST required input. Supervision should ensure the MPM functionality.
4) The crew members need to be informed to ensure the quality of input. The DST input data is the 'raw' data the crewmembers have inserted in the system. Lacking data entries can be easily traced. Feedback should be given to improve future registration.
5) Development of the organisation of information (documents/ interface) to show the quality of FMS' maintenance decision making. A systematic approach to be transparent on the performance drivers (MPM results) and level of optimisation of corresponding cost minimisation problems.
6) Development of the organisation of information to support the short term alignment with OpCo's (budgetary) requirements and commercial project schedule. Maintenance setting analyses need to use the MPM results to support the OpCo in maximising the profits by selecting the best possible organisation of maintenance.
7) Development of the organisation of information to provide feedback on the maintenance realisation to the chief engineer, who is responsible for maintenance aboard the vessel. Quality of data input should be included in the feedback.
8) Initiate the improvement projects with the highest impact on maintenance performance. The recommended maintenance improvement projects:
    a. Systematically optimise repair preparations based on experienced critical failures to reduce the impact of similar failures in the future.
    b. Optimise the crew selection process based on required capacities and competences.
    c. Development of a systematic approach measuring and improving dry dock quality of organisation.
9) The magnitude of direct costs per equipment is revealed by the Operational Expenditures' overviews discussed in the 'Baseline study', Appendix II. However, costs are not linked to maintenance jobs and costs of downtime are not included.
    a. The highest budgets indicate the expected maintenance costs per piece of equipment. Equipment level improvement projects could be initiated to the high cost equipment.
    b. All costs are supposed to be linked to maintenance jobs registered in 'Star'. Transparency in administration could be supported by the MPM results.

7.3 Future research

The comprehensive MPM approach of maintenance is entirely different than current strategy focused MPM standard. Maintenance performance is considered to be optimal when the expected costs are minimised given information available. This thesis provided a MPM approach to fill the gap of practical tools in MPM literature. To develop a practical tool, the focus of the new MPM approach is to align the MPM results with managerial possibilities to influence maintenance performance. The approach seems to fit the general maintenance organisation. Further research to other industries should approve or reject the general applicability.

The comprehensive overview of maintenance costs and maintenance engineering concepts has put strategy in a different perspective. The strategic determined budgets for maintenance are a constraint in implementing the maintenance engineering concepts. The maintenance plan is supposed to minimise the costs of deterioration. It might happen that the budget does not support the optimal maintenance plan. The consequence is that direct maintenance costs need to be reduced, while the risk on downtime increases. The availability of data determines the quality of risk estimations. Further research should study the threshold of MPM data to provide reasonably reliable quantification of the increased risk in order to support budget decisions. It could be the case that risk estimations remain indicative due to a lack of data.

The equipment's design determines, among others, maintainability and expected failure behaviour. A practical approach to estimate the costs of minimising the effects of deterioration needs to be developed. There is no data available on operational performance, so it depends on suppliers' information. The focus should be on the costs calculation of the maintenance plan per piece of equipment. Clearly, the expected costs of downtime need to be taken into account. Expected downtime is involved with the maintainability and expected failure behaviour. Future research should develop a practical tool to map the expected costs and reveal the uncertainties to support the equipment's design decisions.

The value of (preventive) maintenance is defined as "the costs that would have occurred otherwise" (Dekker, 1996, P231; Jones, 2006, P5.6). The value involves analyses of current maintenance settings versus settings that no (preventive) maintenance is carried out. The modelling relies on suppliers' provided information on failure behaviour and costs of maintenance. More operational data increases the reliability of the estimations. Future research should develop a tool to compare the different maintenance settings in order to quantify the value of maintenance.

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Appendix I – Organisational chart Fugro

Fugro Marine Services B.V. (FMS) is a service company within Fugro. Fugro Operating Companies (OpCos) can buy vessel management services of FMS. Fugro does not show an organisational chart in their year reports or on their website (Fugro, 2014a). The organisational chart provides an impression of Fugro's structure.

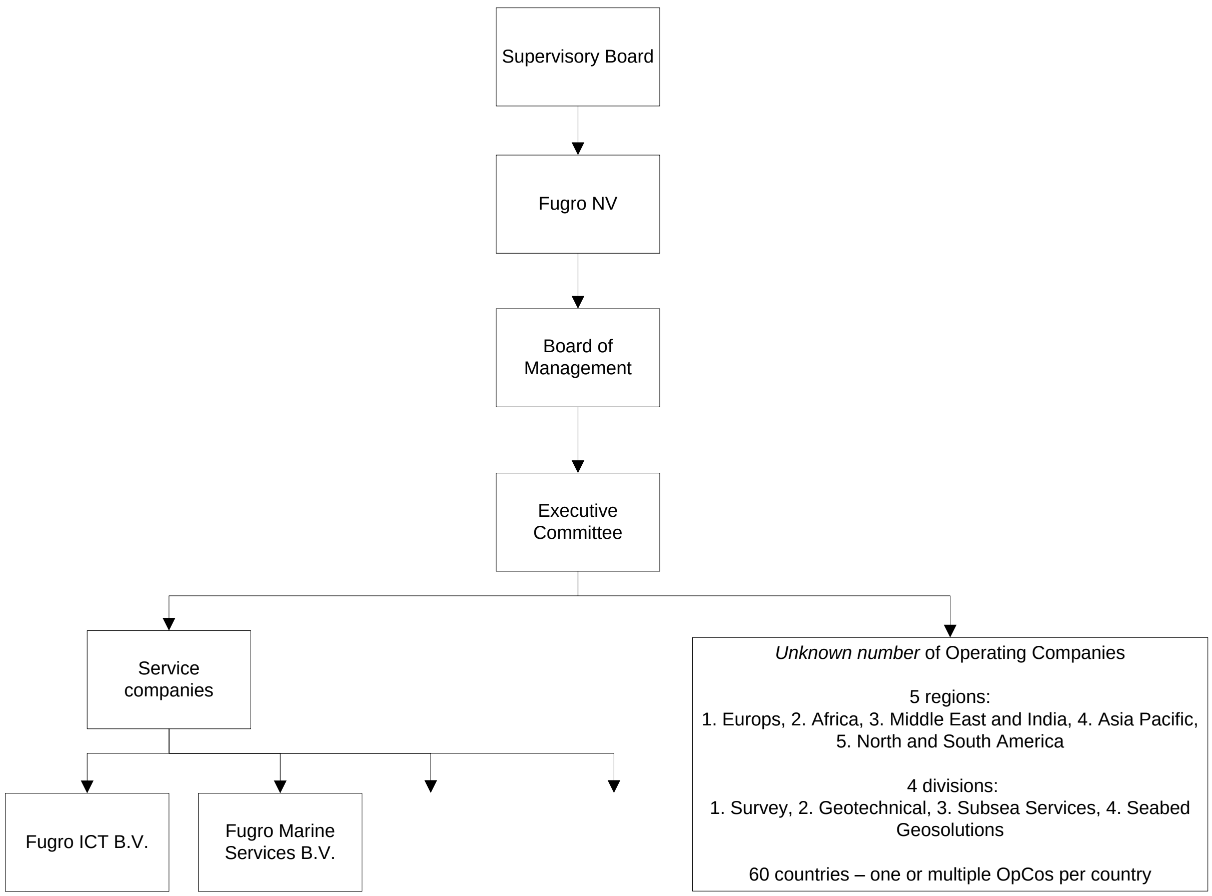

Figure 18 Organizational chart Fugro

At the start of 2014 the executive committee comprised the members of the board of management and the director of the Survey division (Fugro, 2014a).

There are no details on the number or profitability of OpCos. The year report provides separate information on markets, regions and divisions. (Fugro, 2014a)

Appendix II – Baseline study

Baseline study- Fugro Marine Services

MaSeLMa

the practises of an Asset holder

Conducted by Dirk-Jan Fokkens, June 2014, rev. Sept 2014

Supervisors:
Fred Schulte (Fugro)
Matthieu van der Heijden (Universiteit Twente)
Rob Basten (Universiteit Twente)

Contents baseline study

List of abbreviations

BLF Management: Business Line Fleet Management is responsible for the management of the fleet.

BLF Development*:* Business Line Fleet Development is responsible for design and build of new vessels

CMMS**:** Computerized Maintenance Management System, which is integrated in Star IPS.

DDM: Dry Dock maintenance, a period of time of maintenance and an unavailable vessel

FMS: Fugro Marine Services manages the fleet for the Operating Companies of Fugro.

FSSV: The Fugro Standard Survey Vessel is a type of survey vessel of which four are sailing.

HSE system: Health, Safety and Environment is a class necessary system to ensure FMS provides qualitative and safe services

ME: Maintenance Engineering, department of BLFM

MPI: Maintenance Performance Indicator

MPM framework: A framework for Maintenance Performance Measurement contains an overview of MPIs per criteria.

OEM: Original Equipment Manufacturer

OpCo: The Operating Company, which is responsible for the commercial projects of Fugro, is the client of Fugro Marine Services.

QHSE department: The department is responsible for the content of the HSE system and also supports the VSI with the implementation and execution thereof. Q stands for quality.

SIS (Star)**:** Star Information Systems is the software vendor of Star IPS; Star is the package FMS uses to manage its fleet.

SKU**:** a Stock Keeping Unit is a spare part which is kept at stock in the warehouse or at the vessel.

VSI: The Vessel Superintendent is responsible for the performance (HSE, availability & reliability) and subsequent the budget of vessel(s) assigned to his/ her care. He aligns all activities (e.g. maintenance, inspections and audits) required to manage the vessel with the operational schedule of the OpCo.

1 Introduction baseline study Fugro Marine Services

This study is conducted to get insight in current maintenance, service logistic and supply chain practices involved with Fugro Marine Services' marine assets. The study is part of the MaSelMa project and its guidelines are formulated by Tiedo Tinga, Tarkan Tan, Matthieu van der Heijden and Paul van Fenema. The study focuses on a 65m vessel of which four sister vessels are in use: the Fugro Standard Survey Vessel (FSSV). The FSSV is a special developed survey for the commercial projects of the Operating Companies (OpCos). Next to the FSSVs Fugro Marine Services (FMS) manages 13 other vessels. In the future this number is expected to increase.

The baseline study is carried out to reveal the current standards of maintenance and service logistics in the maritime sector. Section 1.1 introduces the business of Fugro. Section 1.2 is about Fugro's vessels. Section 1.3 is about the vessel management service provider FMS. Section 1.4 elaborates on the business model of FMS. Section 1.5 elaborates on the baseline study outline.

1.1 The business of Fugro

In 1962 Fugro is founded. In fifty years Fugro has become a world leading geological specialist. Fugro provides advice to businesses and governments on acquiring natural resources and infrastructural challenges by acquiring, processing and interpreting geological data. To meet clients' needs all over the world, the organisation is decentralized with over 250 offices in over 60 countries. The services are organised in four divisions: Geotechnical, Survey, Subsea services and Geoscience. (Fugro N.V., 2013, p11-12)

1.1.1 The offshore activities – important and challenging

A major part of Fugro's turnover is related to research of the bottom of the sea, which makes the functioning of the supporting fleet an important factor in completing the projects. As the projects are conducted in challenging circumstances, the market requests reliable vessels. To offer Fugro's clients standard high quality and to limit opportunistic behaviour of external vessel managers, Fugro started the in-house vessel managing company Fugro Marine Services in 2005. Since then, the fleet of FMS has grown to 17 vessels.

The projects are not carried out in the middle of the ocean, as the workable depth of the FMS vessels is limited, i.e. the sonar projects could be conducted at a depth from 5 to 2000 meter and AUV projects can be conducted down to a depth of 3000 meter. Four of the five oceans have on average a depth of 4000 meters and the fifth ocean, Arctic Ocean, is partly covered with ice. During summertime the Arctic Ocean is accessible, but it only covers less than 5% of the total ocean surface. There are shallower parts in the middle of the Ocean, for example the underwater ridge of the Atlantic Ocean, which is about 2000-3000 meter depth. (Pearson Education, 2007) But surveys on mountainous areas are not common for Fugro, as there is not much constructed or oil found.

Concluding, in principle there are no projects conducted at the ocean, so the work is restricted to projects nearer to the shores. This enables the vessels to be smaller, because the required capabilities to operate in the middle of the ocean differ. How they differ exactly is beyond the scope of this baseline study.

1.2 Fugro's vessels at the maritime market

There are not many vessels like the FSSVs or the other specialised vessels of Fugro available on the market. Subsequently, the requested maintenance and service logistics at FMS are not common in the maritime market. On one hand they serve a particular group of specialised customers, and on the other hand Fugro Marine Services need suppliers which are more flexible than normally. To get an understanding of the challenges faced, the section starts with an introduction of the interests of Fugro.

1.2.1 Fugro's challenges differ from other asset holders

Fugro Marine Services manages a fleet of 17 different vessels. Seven of the vessels are built to Fugro's special requirements and this year another three are expected to be delivered. The OpCo strives to schedule projects 24/7 when weather permits, as the demand for high-tech survey work is considerable. The vessels need to be in a good condition to conduct the survey projects: vibrations and noise of the equipment of the vessel would interfere with the quality of the geo data recorded. Unexpected breakdowns mean a loss of turnover by the day rate of approximately €35,000 to €70,000. Of course, in the manufacturing industry higher downtime costs of machinery are often faced, but the industrial 'static' environment requires a different approach than the 'dynamic' off shore environment, e.g. compare an high tech production facility in an industrialised area with the supplier located at the same city, with an off-shore project near the shores of Western-Africa. Even food supplies have to be imported in these challenging regions, not to mention special maintenance services or spare parts. Besides in other parts of the maritime industry there is an overflow of assets: when a transportation vessel needs maintenance for a longer time than expected, there are possibilities to arrange replacements in contrast to the specialised vessels of Fugro. (Maribus, 2013, P164-170)

Concluding, the management of highly utilised specialised assets in challenging environments without replacements on the short term is a challenge. An optimal solution to the challenge is not available in the market, as failure data of specialised equipment under specific circumstances is limited by definition.

1.2.2 Long term vision FMS versus short term vision of clients

The customers of FMS form a challenge. Fugro Marine Services strives to optimise availability over the expected 25-year lifetime of a vessel. As vessel management is not a core competence of the Fugro OpCos, they might decide to postpone long term beneficial maintenance due to short term goals. Moreover, the budget holding clients are not conscious of taking maintenance into account when investment decisions need to be made. At present and in future, the OpCos strive to use the vessel as much as possible, so they should take note of the in-house ship manager recommended maintenance. FMS on their turn should keep the OpCo informed on required maintenance in one or two years. Certificate required and suppliers' recommended maintenance can easily be identified up front based on expected running hours and yearly checks. An example for the importance of information sharing: a major overhaul of an engine is expected to take 10-12 days of work in which the OpCo cannot conduct projects.

There exists a lack of priority or interest in maintenance at the OpCos, but FMS is not yet able to proof the necessity of maintenance. Money is the language everyone understands, but it takes expertise to translate preventive maintenance jobs to give a clear concrete added value. For example, the availability of the vessel will be higher when preventive maintenance reduces the failures of critical equipment, but historic data of (comparable) vessels with similar usage patterns is not available. When decisions are made based on the best approximations of effects of required maintenance and expected failures under certain circumstances, the budget holder can decide whether to choose short term profits at the cost of increased future costs. It is important and challenging to define the increased required future maintenance, against the consequence of lower availability, as precise as possible.

1.2.3 Controlling the vessels' availability in conjunction with the suppliers

The importance of vessel availability in combination with the required flexibility due to client's last minute schedule changes due to weather conditions or the acquisition of a new valuable project, does FMS prefer to be in charge of the maintenance planning aboard. Because FMS has a limited number of vessels and needs flexible support of suppliers at dispersed locations in the world, they are themselves also a demanding client. As the leverage of FMS is increasing with an expanding fleet, possibilities of becoming a preferred customer for maintenance, services and provisions can be explored and exploited.

1.2.4 Added value of FMS with respect to other vessel managers

Based on interviews with different experts in the maritime sector is the common approach of ship management in the market short term based. FMS' costs of keeping the vessel available for work during the lifetime costs more than competitive vessel managers could offer to take over the vessel management, as they could choose short term profits. Fugro Marine Services has to proof that they manage the vessels in a significant better way. An increase of availability of the vessel to conduct projects will lead to success, as the clients are enabled to conduct more projects. Section 0 discusses FMS' business model.

1.3 Introduction Fugro Marine Services

The client requires a smoothly sailing vessel. Fleet development designs a vessel which is capable of deploying survey equipment. A global overview of the activities of Fugro Marine Services is displayed in Figure 19.

1.3.1 Design of the vessel

FMS fleet development is responsible for designing a specialized vessel which fits the purposes and the budget of the Operating Company. Moreover, fleet development should integrate the lessons learned concerning vessel design during the operational years under fleet management.

1.3.2 Build of the vessel

The shipyard is required to build the vessel. During building, there is not much to win, but a lot to lose. Fleet development's supervision should take care of the vessel's proper completion and smooth delivery to fleet management.

1.3.3 Preparation for commercial use

The required equipment has to be established and arranged; the information system has to be installed and made fit for the vessel; a well performing crew has to be gathered; and policies have to be clearly constructed. The vessel should be well prepared to stay in business according to the plan. In parallel, the OpCo has to prepare the project equipment.

1.3.4 Maintain marine equipment

The vessel should be kept operational and in class to be able to carry out current and future operations. The vessel superintendent (VSI) is responsible for its vessel and each FMS department for its policies and recommendations. A significant part of the VSI's work is preparing all documentation to proof that the vessel fulfils all class requirements, including the necessary 2.5 yearly dry dock periods.

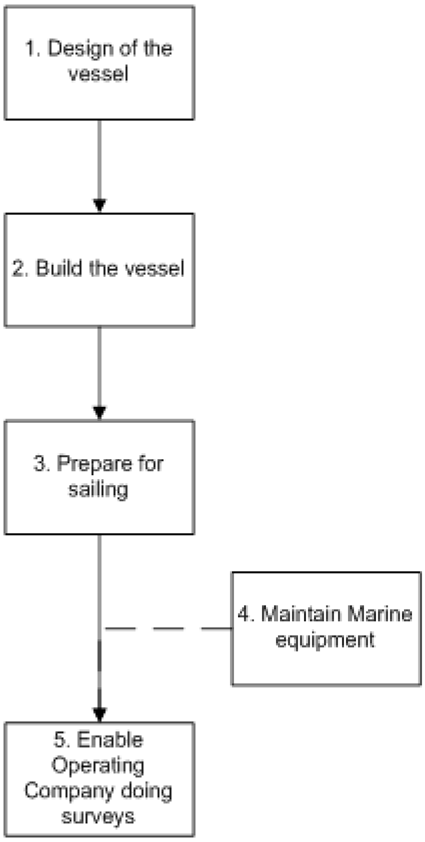

Figure 19 Overview activities FMS

1.3.5 Enable the Operating Company conducting surveys

Uptime of the vessel is profitable when the operating company can work an exploit the vessel an increasing amount of hours. A high utilisation increases the deterioration of the vessels' equipment. Step 3 and 4 of Figure 19 will be repeated according to the project schedule and the maintenance plan.

1.4 Business model

A business model consists of the added value of the company in a Customer Value Proposition and the organization of the added value in the profit formula, the needed key resources and key processes (Johnson et al., 2008, P62). Johnson et al. (2008, P61) state it is useful to start the mapping of the key processes and key resources by the profit formula, because it gives a goal to work towards, see Section 0. FMS' job is to manage the vessels to enable OpCos to conduct projects in a satisfying way.

1.4.1 Customer Value Proposition

Fugro Marine Services supports Fugro's operating companies to conduct geotechnical projects from the vessel. Whether the OpCo already has a vessel or requires a new one, Fugro Marine Services takes care of it. The goal is to keep the availability of the vessel as high as possible, while downtime is planned as beneficial as possible, for example during periods of relatively bad weather. A trustworthy and reliable organisation and image is required to succeed. While vessel managers in other maritime industries easily can find a replacement of marine assets, for example when a vessel is unavailable due to a long period of maintenance due to overdue maintenance; at FMS this means the OpCo cannot conduct projects and consequently misses revenues.

1.4.2 Profit formula

The profit formula generates value through the mapping of the revenue model, the cost structure, the margin model and the resource velocity. All parts are explained in this section, starting at the revenue model.

Revenue model

FMS does not strive for regular profits, but FMS' added value is in increased availability of the fleet. As there is no information available of similar services, it is hard to state upfront what the revenues, i.e. the uren budget and costs, of FMS should be. A continuous learning and improving organisation, supported by measurements of performance show the added value of FMS to the OpCos and the Fugro board.

The service of high availability, under a unified Fugro Marine Services practices and reliable image, in combination with a good price on the market, should be worth the organisational costs made by FMS.

Cost structure

Costs are directly paid for by the OpCo. When the number of vessels under the management of FMS increases, overhead costs can be shared by more vessels and the purchasing department can arrange improved contracts for increased turnover. However, the OpCos are free to choose whether they want to outsource the management or bring it under management of the in-house vessel manager FMS. So FMS requires evidence that it is a better manager than third parties. This could be in terms of availability, flexibility and costs, of which the managerial trade-offs could be set based on clients' preferences.

Margin model

FMS is not striving for direct profits as FMS serves Fugro related businesses. Specific costs per vessel are directly allocated to the operating company. The overhead costs are divided by an allocation model to the vessels in the fleet. When extra money is needed to develop plans and improvements, FMS has to sell the improvement projects to interested OpCos or the overarching Fugro board of directors. In the future, FMS could consider to make some profits to finance the development projects under own management. This could save time which currently is lost due to internal fundraising. However, showing the competence of FMS in measurable terms is much more important.

Resource velocity

Vessels need to last approximately 25 years. The nature of the business is due to the project based way of working short term based. As projects can be really profitable, the condition of the vessel on the long term can be put aside. It is understandable to aim for the short term, because the consequences for the 25 year term are unknown. For example in equipment decisions: one could save money on the investment, while operating costs turn out to be much higher. However, fleet development has not been aware of the effect of such trade-offs.

1.4.3 Key resources FMS

The key resources are needed to deliver the customer value proposition. The description of the needed quantities and qualities of the resources lay outside the scope of this baseline study. However, a global overview is given:

1) The knowledge and capabilities to coordinate the design and build of a vessel.
2) A vessel to support the survey and geotechnical projects of the clients
3) Capable crew to operate and keep the vessel in operational condition.
4) Office personnel:
    a. Vessel Superintendent (VSI), which is responsible for its vessel(s)
    b. Departments to support VSI with use of the resources 5,6,7,8
5) Information System to share information and align the managerial processes
6) Industries' Quality Health Safety Environmental standards implemented.
7) Organisation of maintenance:
    a. Class societies apply a 5 year period for several important certificates and vessel surveys. Moreover, an intermediate survey is also required.
    b. As there is a trade-off between time required for preventive maintenance and corrective maintenance, which both directly influence the availability of the vessel, it is in Fugro's best interest to build the know-how to keep the vessel in a reliable operational condition with the proper amount of maintenance.
    c. The organisation of spare parts and maintenance services.
    d. Knowledge about possibilities suppliers.
    e. Agreements and contracts with suppliers.
8) Relationships (contracts) with suppliers.

1.4.4 Key processes

The key processes of the Business Model exploit the key resources and deliver the Customer Value Proposition. See section 0 for a global overview of the key processes required to support the OpCos to carry out projects.

1.5 Outline baseline study

Chapter 2 discusses the organisation and supply chain of FMS. Chapter 3 is about the current performance of vessel management. Chapter 4 is about FMS' organisation of maintenance. Chapter 5 is about stock management. Chapter 6 concludes on the current fields of interest.

2. The organisation and supply chain of Fugro Marine Services

Fugro Marine Services is managing 17 vessels of the Fugro fleet. All vessels are owned by individual OpCos and the OpCos do not share the fleet capacity, which makes each OpCo depending on the availability of its vessel. FMS' operational practices are described in this chapter.

Section 2.1 provides the organisational chart of FMS and elaborates on the different departments related to vessel management. Section 2.2 is about the interactions with the supply chain.

2.1 Organogram FMS

Fugro Marine Services runs offices in Brazil, Singapore and Leidschendam. In Leidschendam the main quarters are located and policies for FMS are developed. In 2013 52 different vessels (Fugro, 2013) have been involved in supporting OpCos with their services. An increasing part of the vessels is managed by FMS. Currently FMS manages 17 vessels with approximately 75 employees working at the offices, of which 60 are working at Leidschendam.

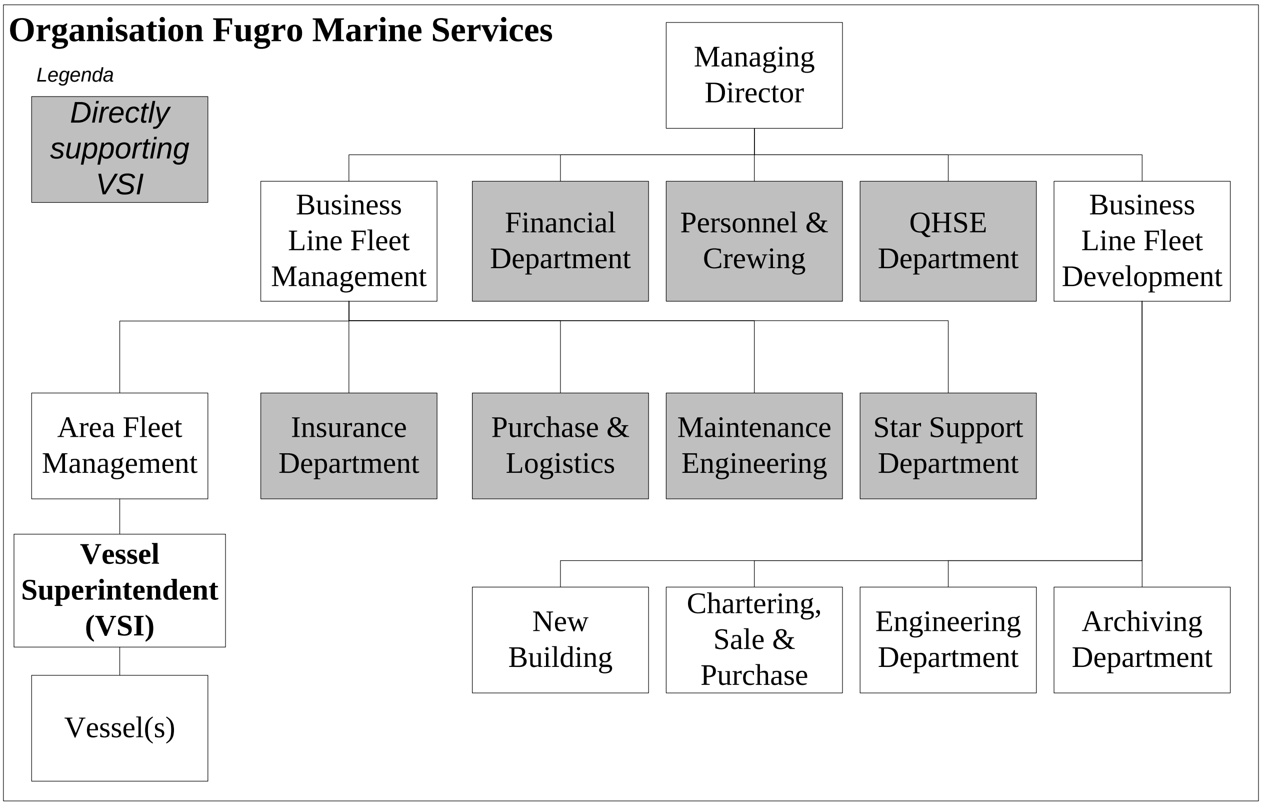

Figure 20 Organogram Fugro Marine Services

Fugro Marine Services exists of the departments shown in Figure 20. The grey blocks are departments which develop policies, templates and manuals, and conduct actions to support the operating vessel. This research is commissioned by the Maintenance & Reliability Engineering (M&RE) department, and requires performance data and knowledge sharing of different FMS' departments. Maintenance related activities are internally involved with Business Line Fleet (BLF) Development with choices for equipment and maintainability of the vessels' design, as well as Business Line Fleet (BLF) Management. The following departments are in some way involved with maintenance: personnel & crewing, purchasing & logistics, Star support department, the VSIs, the crew aboard the vessels and the vessels.

Next, the core activities and maintenance relation of all departments will be mentioned. BLF Management is discussed in Section 2.1.1. BLF Development is discussed in Section 2.1.2. Section 2.1.3 is about the other three departments directly under the managing director. The interaction with the M&RE department is shortly mentioned when applicable.

2.1.1 Business Line Fleet Management
BLF Management manages the vessels. Each vessel is led by one VSI, who is responsible for the performance of his allocated vessel. The FMS fleet is managed by four different offices, led by an area fleet manager, located at the next areas: Abu Dhabi, Brazil, Leidschendam and Singapore. The departments of BLF Management are shortly discussed after the VSI. The activities of the M&RE department are prescribed in Chapter 4.

Vessel superintendent
The VSI is responsible for the organisation of the marine part of the vessel. Each VSI is responsible for 1 to 3 vessels and is advised and supported by the staff of FMS. There are no clear numbers available, but VSIs do swap management of vessels regularly, which pleads for a well-constructed knowledge base. The responsibilities include the alignment of the schedules of the clients and BLF Management, the finances, taking care of meeting all industries' requirements and the preparations of the dry docking periods. The commercial projects need a proper sailing and maintained vessel, to which the VSI is supported by the M&RE department. Whether the VSI invests in the M&RE's maintenance prescriptions, like recommended critical spare parts aboard, also depends on available budgets. When the VSI is not convinced of the necessity, he might postpone the recommended investment. The success of a dry docking period mainly depends on the responsible VSI. The experience of the VSI and his knowledge of the vessel determine whether all necessary jobs are well prepared. Preparations include the arrangements of spare parts, service providers and class society inspectors. When an inspector reveals insufficient parts of the vessel, ad hoc jobs need to be arranged and conducted.

Star Information System – FMS internal Star Support Department
Star Information Systems (SIS) provides maritime software solutions and services (SIS, 2014). The software is referred to as Star. Fugro Marine Services uses Star to manage the vessel. For example, the maintenance planning, availability of spare parts on the vessels and purchase orders can be taken care of using this system. All kind of information about the vessel can be stored by filling out templates or uploading files. The Star Support department prepares Star by filling out the equipment tree (bill of materials) into the system, manages and develops reports for FMS, but is also involved in aligning the needs of FMS with the developers at SIS. Moreover, the Star Support department informs and assists involved parties like the VSI, the crew and the purchasing department.

Someday Star should contain accessible and organised data suitable to base tactical decisions (including the ones concerning maintenance) on. However, suiting the goal of the research, the identification of required data is not yet done. Currently FMS employs over 10 people to use Star and solve problems faced by FMS' employees. Moreover, main improvements concern reports for daily operations and usability of the system, not to mention usable overviews for tactical decision making. The in-house Star department is keeping the system updated with all procedures, products and manuals, and training employees, solving system's bugs or finding solution to work around system's bugs.

Even four of the five M&RE department employees are mainly working on keeping Star updated with all maintenance procedures and prescriptions. A lot of time is consumed by preparing Star for the newly built vessels and new Star developments: for example, a standardised approach for the four FSSVs is not organised upfront, but when a lot of individual work has already been done. On top of those developments, the current methodology does not support improving the current maintenance plan by administrating the right data. As the quality of data relies on the input of the crew, improvements require proper instructions as well.

Purchasing and logistics
The purchasing and logistics department's current practises are limited to carrying out orders of the vessels' crew. The purchasing department processes the orders concerning provisions, spare parts and other goods. The logistics of deliveries from FMS' suppliers to the vessels are outsourced. FMS does not run a warehouse, so orders are directly placed at the supplier. The supply base is not actively managed due to lacking personnel capacity, the four purchasing employees at Leidschendam are mainly utilised by fulfilling the orders and . Long term relationship benefits, including economies of scale, are not exploited.

2.1.2 Business Line Fleet Development

BLF Development is located at the Head Quarters in Leidschendam and designs and builds vessels based on Fugro OpCos' requirements. After the design is finished a tender is organised. After suitable shipyards are found, the contract is concluded with the shipyard which offers the best deal. Although there is FMS supervision, the shipyard is responsible to build the vessel according to the provided specifications. In the past the cooperation with BLF Management has been one of "throwing over the wall", but first steps are undertaken towards a more aligned handover of newly built vessels. Management of BLF Development has mapped the organisation of the trajectory of developing a vessel and identified points of discussion with and receive feedback of BLF Management in an early stage. Concerning integrating lifecycle design decisions into the process is BLF Development ready to receive input, but the M&RE department is not sure what to yield in the rounds of discussion and feedback. However, conscious lifecycle management ought to be company's policy and not solely depend on M&RE department initiatives.

2.1.3 Financial department, Personnel & Crewing and QHSE department

The personnel & crewing department takes care of the vessel's crew and crew changes, planned by the VSI. Next to the taxes and other accounting issues, the financial department registers and provides the overview of the finances. Star is not capable of showing financial overviews, due to lack of inserted financial information on purchases. The financial department does not administrate maintenance job IDs, which makes it hard to track what caused the costs. Moreover, some random checks of costs showed the administration lacks. Some invoices were booked under certain parts of the equipment without any jobs logged at Star.

The FMS' business requires high quality and minimal breakdowns, casualties and pollution. On top of the legal issues concerning vessels, Fugro Marine Services has taken sufficient measures to ensure health and safety for the crew and the environment to satisfy the increasingly demanding market requirements. The QHSE department is in charge of the development of QHSE policies which are needed to get permission to work in the oil industry. Besides, the QHSE department has prescribed to log, among others, whether a vessel is available.

Insurances and legal issues are taken care of at the insurance department. To meet the market requirements concerning quality, health, safety and the environment (QHSE) the VSI is supported by the QHSE department.

2.2 FMS' supply chain

After an overview of the internal organisation, the interaction with external parties is of interest. This section provides an overview of the parties Fugro Marine Services is involved with. There are two main processes distinguishable: firstly, the development and building of the vessel and secondly, the management of the vessel that is in commercial use. In this section the actors and interactions of the actors are explained. A closer look is taken at the supply chain of the FSSVs the Fugro Searcher and the Fugro Galaxy. Other vessels are comparable, but probably have other suppliers involved. This section shows how FMS manages the supply chain for the Operating Company (OpCo) of Fugro. FMS' responsibilities exclude the geotechnical equipment aboard.

Section 2.2.1 shows the actors involved with vessel management. Section 2.2.2 is about the interaction of FMS and its client, the operating company (OpCo). Section 2.2.3 is about the interaction of FMS with a class society. Section 2.2.4 is about the interaction with the shipyard during the vessel build fase. Section 2.2.5 is about the interaction of FMS with the suppliers during the lifespan of a vessel.

2.2.1 The actors in the service supply chain

The actors involved in the supply chain are shown in Figure 21. The prime activities of the actors with the FSSV are explained per actor. After an introduction of the actors, the relationships are shortly highlighted. The main difference between the supply chain of BLF Development and BLF Management is the role of the shipyard. A shipyard in control of the building of a vessel has its own set of preferred suppliers that do not need to match FMS' preferred suppliers. The effect is that the set of suppliers per vessel may differ due to reasons other than supplier selections based on certain competences and quality.

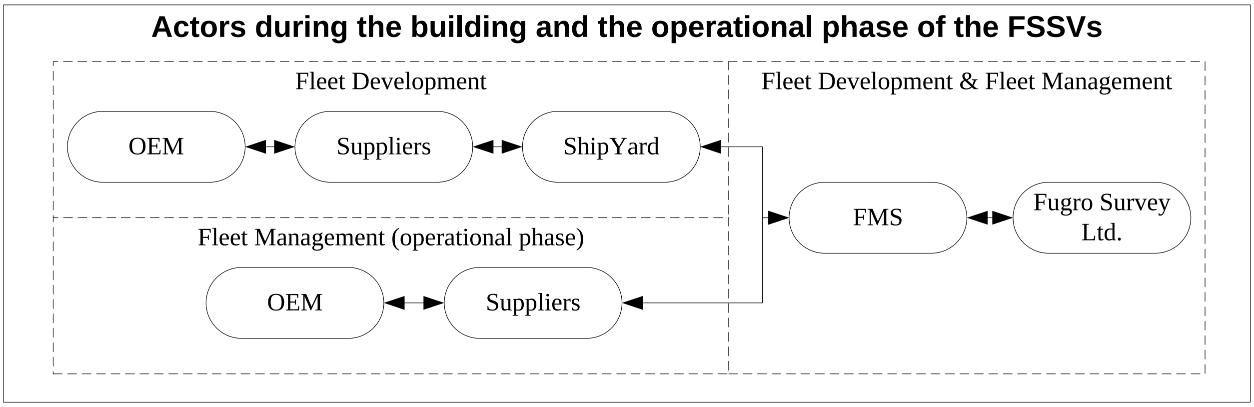

Figure 21 Actors in the supply chain of the vessels for Fugro Survey Ltd.

The interactions of FMS are discussed in the following sections.

2.2.2 Interaction FMS and an OpCo

Fugro Marine Services is a service providing company for the Fugro OpCos that decide to cooperate with the in-house vessel manager. The OpCo usually owns the vessel.

Client of Fugro Searcher and Fugro Galaxy is also the owner: Fugro Survey Ltd.

There are two ways to become an FMS client: one is to swap management of an existing vessel, the other is to order Fleet Development to design and build a new vessel. The owner of the Fugro Searcher and the Fugro Galaxy is Fugro Survey Ltd., located at Aberdeen Scotland and Great Yearmouth, England. Fugro Survey Ltd. operates primarily on the North West European Continental Shelf, Mediterranean and West Africa regions (Fugro Survey, 2014). The client's clients are companies that need hydrographic and geophysical survey services, which can take a couple of weeks to a couple of months to carry out.

Interaction Business Line Fleet (BLF) Development and a client

BLF Development organises the development and construction of new vessels. So far, there have been 7 vessels built by BLF Development. All vessels are built upon request of a client. The client decides on the budget and might in cases of an exceeding budget, take the quote and decide to change the design.

Current decision making is not consciously taking into account all expected operational costs. For example, the expected and recommended maintenance is left out the scope. For example, the engines of the FSSVs have been selected because of a lower sound level, a lower usage of diesel and a low initial purchase price, of which the latter is beneficial for the shipyard. Unfortunately, the engines' recommended maintenance plan is unrealisable due to time and costs and had to be adjusted. Adjusted maintenance schedules usually preclude successful guarantee claims and therefore did not play a beneficial role when the Fugro Galaxy's engine needed to be replaced in 2012.

When a guarantee claim fails, the unexpected maintenance costs will be paid for by the OpCo. As FMS did not point out the problem with the unachievable recommended maintenance when the engine was selected, the failed claim worsens the appreciation of FMS.

Interaction Fleet Management and a client
The VSI communicates with the client. The interactions concern the approval of the budgets for yearly Operation Expenditures and custom plans for Capital Expenditures projects. Besides, the alignment of FMS' schedule of maintenance and inspections with the project schedule of the client is important.

2.2.3 Interaction FMS & Class societies
A class society acts on behalf of a state or on behalf of members of the Oil and Gas industry. The class society judges whether a vessel is properly managed and maintained to be allowed to sail under the state's flag or operate in the industry. The licence to operate of one vessel at FMS contains 15 class certificates that are valid for approximately 5 years and needs to pass 13 different yearly and 37 five-yearly surveys. The maintenance consequence of the extensive class surveys to get an approval is the emphasis on funded plans for maintenance. When FMS proves certain maintenance approaches are safe and reliable, almost everything is possible. For example, condition based maintenance is considered as a proper level of standards. However, the surveys and classification rely on checking procedures and the physical appearances of the vessel, the information system and the office. An approval of the maintenance plan does not mean that the actual organisation is effective or efficient.

2.2.4 BLF Development specific supply chain: interaction shipyard
When the design is made, BLF Development organises a tender to retrieve quotations of shipyards to build its vessel. In case of the FSSVs the shipyard Fassmer has been contracted. When the Fugro Searcher and the Fugro Galaxy were ordered to build, BLF Development did not have the time to find the best suppliers and lacked experience with suppliers. The shipyard had an extensive role in selecting suppliers for building the vessel, however not all suppliers have been satisfactory. Therefore, current practises are more towards a preferred suppliers' list in consultation with parties of BLF Management. As the shipyard usually also has a preference for certain suppliers, BLF Development selects in conjunction with the shipyard the final suppliers.

2.2.5 BLF management specific supply chain: interaction suppliers
To keep the vessel sailing, provisions, spare parts and services have to be arranged. When provisions or services are ordered via the information system Star, quotations are requested from suppliers. Purchasing arranges provisions and materials; the vessel superintendents arrange the services individually.

The challenge of dispersed locations
Although there are lists of preferred suppliers, these suppliers are not awarded with long term contracts. Consequently FMS does not obtain long term relationship benefits.

When some economies of scale are strived for, the challenge of different vessels with different equipment located at different locations in the world has to be coped with. Framework contracts for several vessels need flexible international operating suppliers.

Suppliers' contracts are not a priority at FMS. Currently all orders, even periodic orders, have to be manually ordered each time anything is needed. This is a lot of work for the crew and the purchasing and logistics department. Internal standardised periodic delivery of a selection of provisions is the last development. The current focus is the internal organisation of the periodical ordering.

As the arrangements with the suppliers do not depend on the internal organisation, the supplier selection could be started. It is unknown when suppliers are going to be managed by contracts with possible service level agreements.

OEM & service suppliers

Some suppliers are Original Equipment Manufacturers (OEM), but some suppliers act on behalf of an OEM. For example, in the case of the engines of the FSSVs, the OEM, Mitsubishi, did not want to do a marine specific recommendation. So BLF Management was forced to retrieve information of a service supplier which is capable of overhauls of the specific engines. The result was an achievable schedule in terms of maintenance, but when the engine had to be replaced due to an unknown reason, the OEM did not feel responsible and the service supplier could not be held responsible as they just advised on the matter. Of course, only a limited selection of equipment is worth the resources of extensive operational analyses at the equipment selection phase.

3 Performance FMS- FSSVs

This section provides an overview of the FSSV usage and an overview of the average yearly costs. Both improve the understanding of the opportunities to improve the FMS (maintenance) operations.

Section 3.1 is about the use of the vessel. Section 3.2 is about yearly costs involved with vessel management. Section 3.3 is about the core business of vessel management: the availability of the vessel.

3.1 Use of the vessel

Three types of actions of a vessel can be distinguished. The vessel can be active in a commercial project, lying for anchor inside or outside a port and the vessel can be in transit towards a new location. The separate logging of transit and operation is also of interest for maintenance purposes, because the load on the vessel is truly different. When the vessel is in transit, the goal is to arrive as soon as possible, which results in high load on the engines. When the vessel is in operation, suitable dynamic positioning equipment keeps the required course and speed precisely. This results in reduced loads on the engines. The specific differences of loads on the vessels are outside the scope of this research. Table 6 shows the distribution of time over the three actions.

Action	Range percentages yearly actions of FSSV	Average
Port/ Anchor	Varying from 30% to 42% per year	34%
Transit	Varying from 12% to 26% per year	17%
Operation	Varying from 43% to 56% per year	49%

Table 6 Overview actions

Table 6 shows a remarkable long time spent at lying for anchor. Namely 30% to 42% is equal to 109 to 153 days per year. The time spent lying for anchor is of interest, because it provides a maintenance opportunity. A maintenance opportunity is a moment of time the vessel is out of operation due to other reasons than that of maintenance. Depending on the expected duration of anchoring time, varying maintenance jobs that require the vessel to be out of operation might be conducted without causing additional downtime. Although the actual reasons for lying for anchor are not logged, an indication of possible reasons shows that the weather conditions have a large impact on the total anchoring time. An overview of the causes of anchoring time is given in Figure 22. The approximation of the distribution of the anchor time is supported by the responsible VSI.

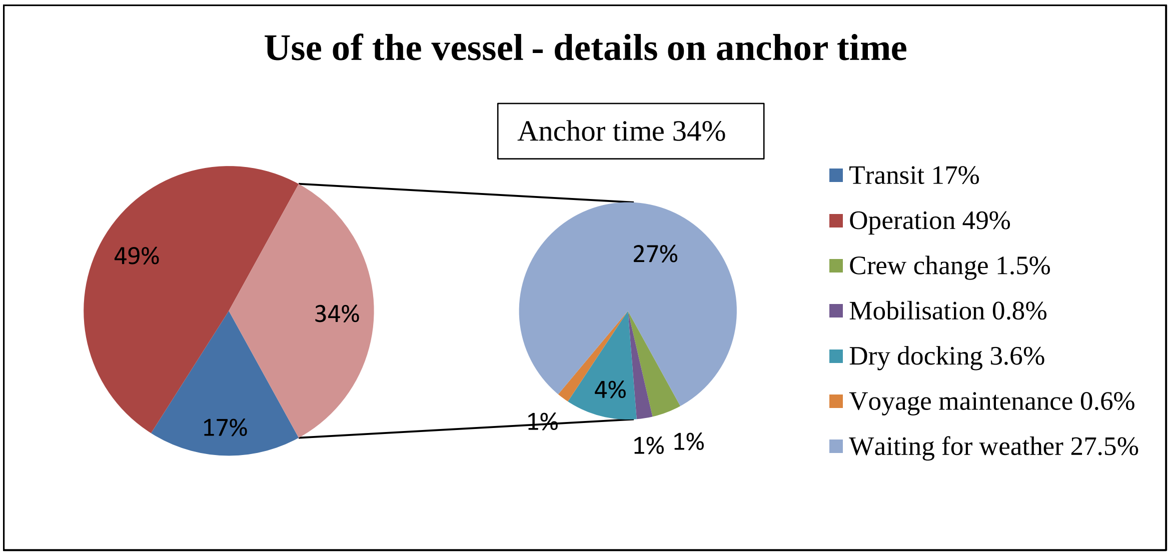

Figure 22 Overview use of the vessel with details on anchor time

To start, each vessel has 2 crews, which rotate every 4 weeks. A crew change requires about 10 hours. As there are 52 weeks in a year, 13 crew changes require approximately 130 hours, which is 1.5% of a year. Secondly, the amount of projects varies from 5 to 10 projects a year. For example, in 2012 the Fugro Searcher has conducted 6 projects and the Fugro Galaxy finished 7. The preparation of a vessel for a project, which is called 'mobilisation', usually takes 8 to 12 hours. Assuming that the mobilisation of the vessel for 7 projects requires 10 hours on average, the 70 hours are accountable for 0.8% yearly time. Thirdly, the time spent at the dry dock has been on average 320 hours (3.6% yearly time). Fourthly, the time spent at voyage maintenance and downtime repairs has been on average 50 hours (0.6% yearly time). Concluding, only 6.5% is anchoring time due to organisational reasons. The other 27.5% seems to be caused by bad weather. The time spent on "waiting for weather" explains the importance of an available vessel when the weather is good: the employees have to be paid regardless the weather, but revenues are linked to the finishing of projects.

3.2 Yearly costs

Text is limited to percentages for confidentiality reasons

Figure 23 shows the division of yearly costs to manage a FSSV at FMS.

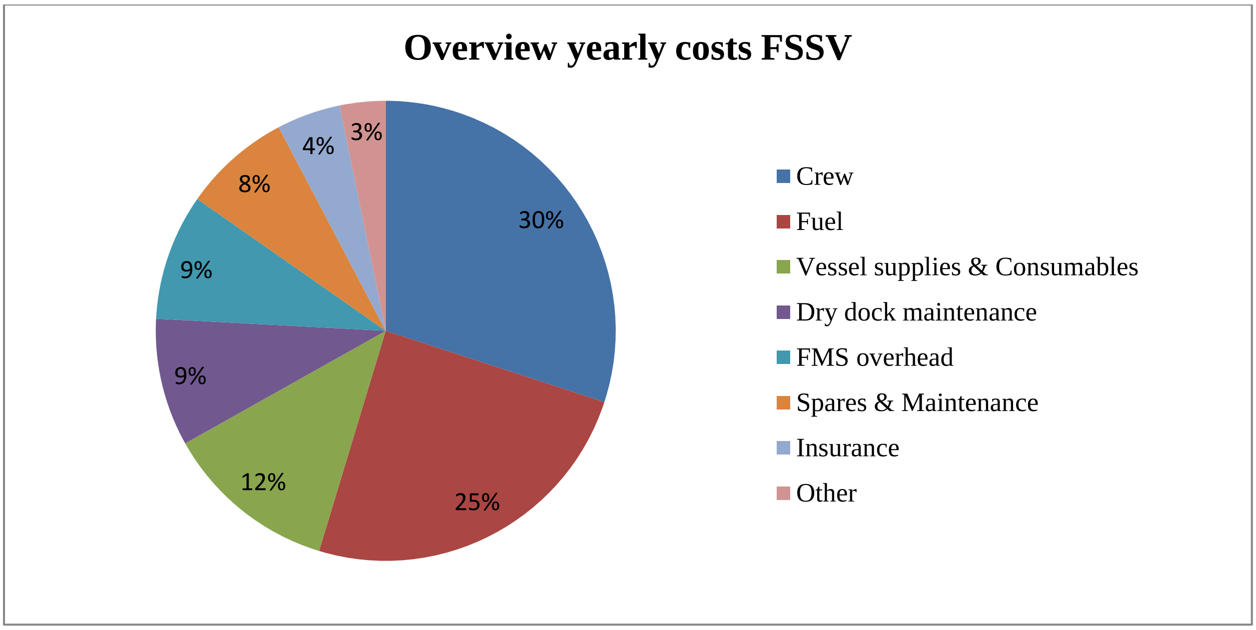

Figure 23 Overview yearly costs division

The costs of maintenance are of interest. At first sight these seem to be limited to 9% of dry docking maintenance and 8% of Spares & Maintenance. However, a lot of preventive maintenance is conducted by the crew (details Section 2.4), so the 30% is also of interest. Moreover FMS internal organisation of handling purchases has marked regularly used spare parts as consumables. Details on what is directly involved with maintenance are not available. Per cost of interest a short description, starting at the highest costs:

Approximately half of the 11 person crew, that is responsible for 30% of the costs, is involved with the maintenance jobs. However, a possible reduction of maintenance jobs does not directly lead to a decrease in personnel costs, as most of these employees are required to keep the vessel sailing. Depending on required competences for maintenance and sailing, FMS could choose to change the crew composition.

An overview of used and bought spare parts is unavailable. However, only a small portion is expected to be related to maintenance of the 12% spent on Supplies & Consumables.

The dry docking maintenance (DDM) costs consist of the expected yearly average dry docking costs during a 5-year docking cycle. The cycle includes an intermediate DDM after 2.5 years and a major DDM after 5 years. This DDM schedule is compliant with the required checks and class societies' certificates to operate off-shore.

The 8% costs for Spares & Maintenance include the costs for external services and spare parts. Which services and associated equipment have contributed to the costs is not accessible, as Star excludes financial information. Moreover, manually sampling of high costs on the opex overview revealed that booked costs do not necessarily accompany jobs stored in Star.

3.3 Current availability FSSVs

In general, the availability of the vessels to support OpCos conducting projects is most important in the assessment of FMS' performance. Also the previous discussed costs are important, as the reduced costs of downtime (increased availability) should exceed the maintenance costs.

Management has stated 98% availability for all vessels as the yearly goal. This target excludes planned dry docking maintenance. There are two critiques mentioned for a general goal, based on the requirements of the stakeholders.

To start, availability during bad weather is not in the interest of the OpCos. The vessel needs to be available when weather is permitting and a commercial project can be conducted. The distinction between types of breakdowns, i.e. concerning critical parts during operations or anchoring, is not explicitly made. When the distinction is not explicitly made, it is in FMS interest to keep the off-project failures out of the reports. For reliability engineering and maintenance management purposes it is necessary that all failures are logged. Also external reports can benefit from transparency of solved issues outside commercial project time. It shows the vessel managing competences of FMS.

Second critique is that the failure behaviour of the vessels differs over the lifetime. When the distinction is not made, the effort of the VSIs in managing the vessels is not righteously judged. Keeping an old vessel on 96% could be much more difficult than keeping a new vessel on 99%. This is because the availability is a result of uncontrollable variables like vessel's age, load, equipment characteristics and controllable variables like the maintenance organisational skills and the quality of the conducted maintenance. It is in the OpCos (FMS' clients) interest that conducted maintenance and the organisational skills are linked to the availability and costs. High quality maintenance can be obtained by competent crew, external services or improved by mechanical engineers. The performance measuring of the organisation of maintenance is subject of this thesis, as the management decisions play a central role in the proposed performance measurement.

Concluding, a general goal for all vessels does not make sense, as achieving the goal does not guarantee well organised maintenance with an efficient use of resources. To determine an efficient use of resources for maintenance, details are required. Required data is identified by this research, but the optimisation (the determination of what is good) based on the data is outside the scope of this research.

The availability of the Fugro Searcher and the Fugro Galaxy is shown in Table 7.

	Availability Searcher			**Availability Galaxy**		
	2011	*2012*	*2013*	*2011*	*2012*	*2013*
Hours dry dock maintenance (DDM)	517	0	0	0	372	0
Yearly hours minus DDM	8243	8760	8760	7296	8388	8760
Downtime (h)	39	48,05	4	2,25	0	126,4
Availability (excluding DDM)	99,5%	99,5%	100,0%	100,0%	100,0%	98,6%
Availability (including DDM)	93,3%	99,5%	100,0%	100,0%	95,6%	98,6%

Table 7 Availability of the FSSVs

Table 7 is based on daily operating records retrieved by the QHSE department and the mentioned downtime is commercial downtime. Two points are worth mentioning. First point is the early intermediate periods of dry docking maintenance (DDM) for both the vessels. Secondly the limited number of failures:

The Fugro Searcher's 93.3% and the Fugro Galaxy's 95.6% availability including DDM had to do with start-up failures of the vessel. It is common that new ships have start-up failures, but from the mistakes should be learned. The Fugro Searcher had to adjust engineering issues and the Fugro Galaxy had to replace an engine. Important is to share the experiences with BLF Development.

The examination of the causes of the downtime of Table 7 has indicated seven different causes. Next to the failure of the engine, electronic systems failed. No system failed more than once, which clearly does not provide suitable data to examine failure behaviour of the involved equipment.

4 Details on Maintenance

So far, an overview of internal and external involved parties and the vessels' performance concerning the availability and the costs has been given. Concerning the FSSVs, there is no immediate need to improve performance of maintenance, because availability is high and maintenance contribution to costs seem to be limited. However, this section shows that current organisation and spending is not based on consciously made quantitative supported decisions, but by experience. Experience is a good starting point, but no proof for an efficient organisation. Improvements for the initially experience based maintenance plan require data and analyses, which is included in the deliverable of the research.

The maintenance plan is the result of M&RE departments' managerial maintenance decisions, based on suppliers' recommendations. The maintenance plan is discussed in three sections, one for each maintenance domain: Section 4.1 is about the planning of maintenance. Section 4.2 discusses the maintenance plan. Section 4.3 is about the maintenance strategies to deal with deterioration. Section 4.4 is about the workload of the crew. Section 4.5 is about the direct costs of maintenance according to the operational expenditures.

4.1 Planning of maintenance – exploiting opportunities

As a guideline, the VSI yearly has 10 days to conduct planned maintenance which requires anchoring in a port or going for a dry dock period. However, the availability of the vessel has been very high, up to 100% in some years, while this chapter points out there are a lot of maintenance related jobs conducted. This suggests that the crew is capable of finding moments to conduct the maintenance jobs without interfering with the OpCo's projects; with the on average 122 days of anchor time there are a lot of maintenance opportunities (see page 73, Table 6). In principle, the vessel is always involved in a project, so the previous stated 7 days of weather forecast, form the period on which the external capabilities of service suppliers can be exploited. As the dry dock periods take longer periods of time and docking capacities, these periods need to be planned upfront regardless the weather. Of course, the dry docking periods could be arranged during periods in which the weather is expected to be worse.

Most jobs are conducted individually as the jobs are involved with one piece of equipment. Therefore, opportunities to share work to prepare maintenance jobs (set-ups) are limited. In a dry dock period, the dry dock set-up is already shared when the VSI did all preparations.

4.2 FMS' maintenance plan

Whether it is possible to conduct preventive maintenance or corrective maintenance depends on the equipment and the involved suppliers. The maintenance is based on the criticality of the components of the system. The criticality is assessed by FMECAs (Failure Mode, Effect and Criticality Analyses). Based on these FMECAs and the recommended maintenance by the supplier it is prescribed what the maintenance and the spare parts should be. When the recommended maintenance is not suitable, the maintenance is adjusted on experience and other experts' advice. For each vessel there is an overview of the different components, criticality and recommended maintenance. When it is not feasible to take the recommended spare parts aboard, options are to store the spares at a warehouse or at the supplier. Currently there hardly any spares at a warehouse or a supplier. However, first arrangements of centralised stock are taken. Reassessments of criticality are done when major conversions are executed or equipment is renewed.

4.3 Maintenance strategies

Per strategy of maintenance is discussed whether the strategy is applied by FMS. Some equipment runs to failure, like the electronic equipment at the bridge. Per vessel are on average approximately 1500 maintenance jobs conducted at the FSSVs. However, only 8% of the jobs clearly require spare parts. A lot of logged jobs are extensive inspections, although the lack of administration does not rule out any use of spare parts. It is currently not known what resources, like employees' time or external costs, are required, so the planning possibilities are limited.

4.3.1 Corrective maintenance
Approximately 6% of the jobs on the FSSVs are corrective. The corrective maintenance varies from the replacement of the coffee machine to the overhaul of a failed engine while at dry dock.

4.3.2 Time based maintenance
As a lot of jobs need to be finished each week, month or year, time based maintenance is conducted. Approximately 93% of all jobs are time-based. A lot of maintenance jobs are about checking whether a certain part of equipment still works properly. Usually the prescribed steps described in the maintenance manual are followed. When an error occurs during such an inspection, steps will be undertaken to solve the error. It is not logged how often a replacement is conducted during a check.

4.3.3 Usage based maintenance
FMS applies usage based maintenance. The running hours are logged for 58 pieces of equipment like hydraulic and oil pumps, the generator and propulsion engines and several compressors. The most expensive jobs are based on their usage: the overhauls of engines are prescribed based on the hours the engine has run. However, most logs are for the statistics as jobs are scheduled on time (for example yearly inspections or a 2.5-yearly overhaul), usually the usage based maintenance will be limited to at most 1%.

4.3.4 Load based maintenance
Although FMS has data available on loads of the engine, this is not used in the planning of maintenance.

4.3.5 Condition based maintenance
Condition based maintenance is about conducting the maintenance just in time to prevent that the performance drops below a certain arbitrary chosen limit. The most expensive marine equipment aboard are the engines. The condition is measured in different ways. The condition of the engine is monitored by lub-oil and fuel analyses, endoscopic inspections, performance tests and vibration monitoring. While condition of the engine is monitored, it is not yet possible to adapt the overhauls upon the values measured. When the overhaul would be still conducted in time, without a large chance on failure, needs to be investigated. High-speed engines need more maintenance than low-speed engines. Personnel are usually more experienced with the marine common low-speed engines. It is expected that future technological developments require more external maintenance services, which probably includes practises of condition based maintenance.

4.4 Maintenance– division of crew workload
In Star maintenance is planned and logged. Although a lot of maintenance jobs are stored in the system, not all daily routine checks are logged. Nevertheless, the stored maintenance jobs will provide an indication of the division of workload. The costs involved with the conducted maintenance by the vessel's crew are captured in the total costs of crew. Moreover, the time used to conduct the job is not recorded, so a cost allocation based on personnel costs and time is not possible.

Due to changes in usage of Star and definitions have changed, information of last year provides the best indication of the workload. Three FSSVs have been sailing the entire year of 2013. On average there have been approximately 1500 jobs per year. However, the division of jobs is just an indication of the workload; the time needed per job is not logged. The logging of jobs is planned to start this year, 2014, because the management has to proof that all the crew is required to conduct the jobs shown in Figure 24.

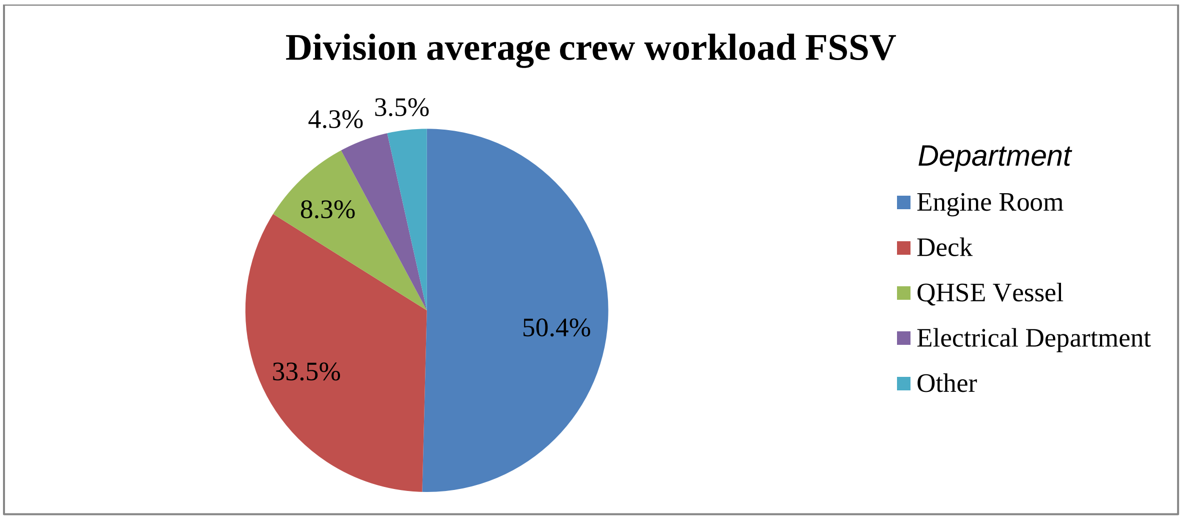

Figure 24 The average division of 1500 jobs over the departments as laid at Star

The variance of the workload is shown in Table 8. The largest part of the work is conducted at the Engine Room and on Deck. The Electrical Department has a high variance due to the first year of sailing of the Fugro Equator: the electronics required extra maintenance.

Department	Range of the number of jobs (workload)
Engine Room	The workload varies in between 43.8% and 56.5%
Deck	The workload varies in between 28.8% and 38.4%
QHSE Vessel	The workload varies in between 6.2% and 10.6%
Electrical Department	The workload varies in between 0.4% and 11.5%
Other	The workload varies in between 2.3% and 5.3%

Table 8 Department's workload variance of 1500 jobs in 2013

The availability of the vessels has been high during 2011-2013. As experienced sailors expect that the start-up failures will be reduced the following years, availability is not expected to cause difficulties. Table 9 shows conducted corrective and preventive maintenance.

Description	Average	Range, part of 1500 conducted jobs
Corrective maintenance	5.5%	Varies between 2.9% and 8.0%
Preventive maintenance	94.5%	Varies between 92.0% and 97.1%

Table 9 Preventive and corrective maintenance jobs according to Star

On average 94.5% of the maintenance jobs is conducted on schedule to extend the lifetime of the maintenance equipment. The preventive jobs are mainly checks, inspections, tests and cleaning and probably take less time than the corrective maintenance, which include problem diagnosis, time to get the spare part, repair and testing. There is no time registered per maintenance job, so the approximately 82 (5.5% of 1500) jobs will probably take more than 5.5% time spent on maintenance. As the availability has been high, it is not necessary to log the time per maintenance to find improved ways of conducting maintenance jobs.

However, logging the durations of the jobs could have other benefits. For example, the average time to get a spare part shows the performance of the purchasing department and involved suppliers. Moreover crew capacity could be adjusted to cope with the required maintenance.

Although it is known how many overdue jobs currently exist per vessel, it is not stored over a period of time. Overdue jobs could correlate with low availability, bad scheduling habits or an underperforming crew; this needs to be investigated.

4.5 Maintenance – maintenance costs

Fugro Marine Services its mission is to become the preferred supplier of Fugro in managing the different types of vessels used. In the eight years the portfolio has grown from scratch to 17 vessels. With the usage of approximately 60 vessels by Fugro, the potential is to triple the current managed fleet. The section starts with an overview of the most expensive components, as that indicates the budget relevant parts of the vessel which are involved with actions in the supply chain.

Text is removed for confidentiality reasons

There is a distinction between diesel engines and propulsion equipment. The 3 diesel engines aboard are for the electrical power production, while the propulsion equipment has 2 electrical propulsion engines, which use the power produced by the diesel engines.

4.5.1 Maintenance services cost

The costs of maintenance according to the operational expenditures are shown in Figure 24.

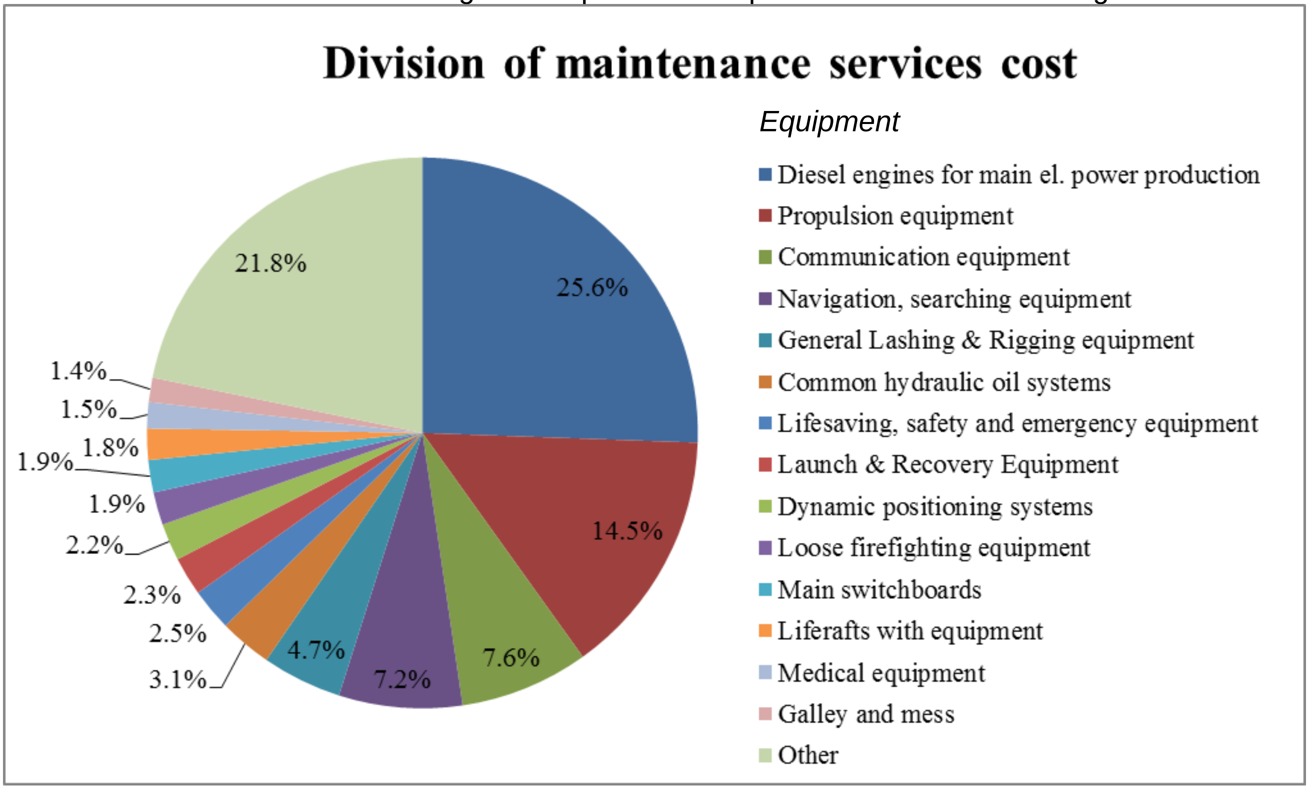

Figure 25 Overview costs per type of equipment according to the OpEx overviews

Per cost is discussed whether the percentage of external costs paid is worth a further investigation of the maintenance plan. It should be kept in mind that its solely based on the external expenses. Figure 25 identifies the diesel engines for main electrical power production as the most expensive equipment. This is caused by high costs of overhauls. Of interest is that the current maintenance plan extents the length of the interval of overhauls by 2.5 times. The costs would be much higher when the suppliers' recommended maintenance schedule would be followed. Condition based maintenance and the associated just in time maintenance, could decrease the total costs, including the costs of downtime.

The second largest cost is the propulsion equipment. The propulsion equipment includes the electric engine, hydraulic installation and the thrusters, which is maintained during the major dry docking period every five years. The difference between diesel engines and propulsion equipment is the following: the 3 diesel engines aboard are for the electrical power production, while the vessels propulsion depends on 2 electrical propulsion engines. The propulsion engines use the power produced by the diesel engines. Condition based maintenance could decrease the total costs, including the costs of downtime. Additional challenge is the requirement for the vessel to be laid up in a dry dock to enable maintenance.

On the third and fourth largest types of equipment, the communication, navigation and searching equipment, the maintenance approach is run to failure or time based replacements. Due to the electronics involved, the possibilities of condition based maintenance are limited. Electronics' failure behaviour does not depend on time, which means that the expectation of a failure in the next period of time is equal.

The maintenance of general lashing & rigging equipment is time-based and replaced when the condition is insufficient. As the costs are only 4.7%, the increased risks of accidents due to breaking lashes are not worth the potential savings.

The costs below 4.7% do not seem to be worth an investigation to adjust the recommended suppliers' maintenance. When the equipment fails, the root cause analysis, which is conducted, might require further investigation to prevent the failures.

4.5.2 Expected lifetime costs diesel engines

The maintenance service costs of diesel engines have a high impact on the total expenses, but the costs vary as the overhauls are not conducted every year. A major overhaul planned every 30,000 running hours costs approximately €100,000 according to supplier's recommendation. Table 10 shows the estimated costs for the three engines of the FSSV aboard, during the lifecycle of a vessel, based on the running hours the Fugro Searcher has made in the years 2010-2013. The total costs are expected to be nearly 1.7 million euro's for a running time of 25 years. The average costs per year is expected to be € 70,000 per diesel engine for electric power production aboard.

Description	Number	Units
Average total running hours for 3 engines on 1 day	31.1	Hours
Maintenance cycle engine	60000	Hours
Approximated needed hours in 25 years (rounded upwards) (31,1 hours/ day * 365 days/ year * 25 years)	300000	Hours
Approximated number of maintenance cycles	5	Pieces
Maintenance costs during maintenance cycle	€ 350,000	Euro's
Total costs 5 cycles	€ 1,750,000	Euro's
Average expected costs per year (25 years)	€ 70,000	Euro's

Table 10 Specifics expected vessel lifetime engine costs

Table 10 is based on a preferred supplier's proposal. The expected running hours are based on the 4 years the Fugro Searcher has been sailing since 2010.

The expected costs are excluding any unexpected maintenance. The utilisation of the vessels differs. A varying time working at operations will have a varying effect on the required maintenance. For example, the engines are lightly loaded during a project, as the FSSV sails on a relatively low speed. Due to the bad burning of the diesel, the oil is contaminated and this affects the condition of the engine. Although the supplier recommends running the engines often on full load to clean the oil, this is not done as frequently as prescribed (every two hours for fifteen minutes). For example, some low speed runs can last a couple of straight days or last over a week. In short, the engines for electricity are badly used during times of anchoring and projects. This mainly is a design failure; the power of the engines is too high for 83% of the time.

4.5.3 Challenges in optimising maintenance schedules for engines

The OEM standard maintenance manual is not applied to marine activities and the supplier is unwilling to do a reasonable estimation due to the niche market the high-running engines at the marine market is. The difference in recommendation of the OEM and the current service provider is large. The OEM recommends to execute the large overhaul, which is the most expensive maintenance job of €100,000 euro, after 8,000 hours, while FMS has planned the large overhaul after 30,000 hours. As some minor jobs are not planned in this OEM schedule, we could state that the OEM maintenance costs would be 3 times the €70,000 per year in our case of 31.1 running hours per day, which is over €210,000 per year. Regardless the involved costs, the operating time lost in case of the schedule of the OEM would be unacceptable. Unfortunately the OEM is not willing to take a closer look to the marine circumstances due to the limited size of the market. To prevent failures due to deferred maintenance of the diesel engines, FMS would fancy taking into account the condition of the engines in determining the moment of maintenance.

5 Stock management

This chapter is about stock management. Stock management is about the stock aboard the vessel. The shipping of spare parts and provisions is outsourced to a third party, from now on referred to as 'the warehouse'. At the warehouse, there is no stock stored which isn't explicitly ordered by a vessel.

Section 5.1 is about the organisation of stock aboard. Section 5.2 is about purchasing and replenishments. Section 5.3 is about the suppliers.

5.1 Organisation of stock aboard

Section 5.1.1 is about the spare parts and tools aboard. Section 5.1.2 is about the usage of spare parts and tools. Section 5.1.3 provides the plans regarding spare parts selection. Section 5.1.4 provides the stock value. Section 5.1.5 is about risk pooling. Section 5.1.6 is about the last time buy.

5.1.1 Equipment to store

There are nearly 10,000 spare parts of equipment of the FSSV in Star. Based on the criticality analysis and the recommended spare parts of the supplier, a selection of approximately 850 spare parts is put on stock aboard. Each type of spare parts aboard is a Stock Keeping Unit (SKU). Next to the critical parts, the crew stores another 150 SKUs. 87.5% of SKUs' prices is known, the other need to be estimated. The total value of the spare parts aboard according to the available purchase prices is approximately €381,000 per vessel.

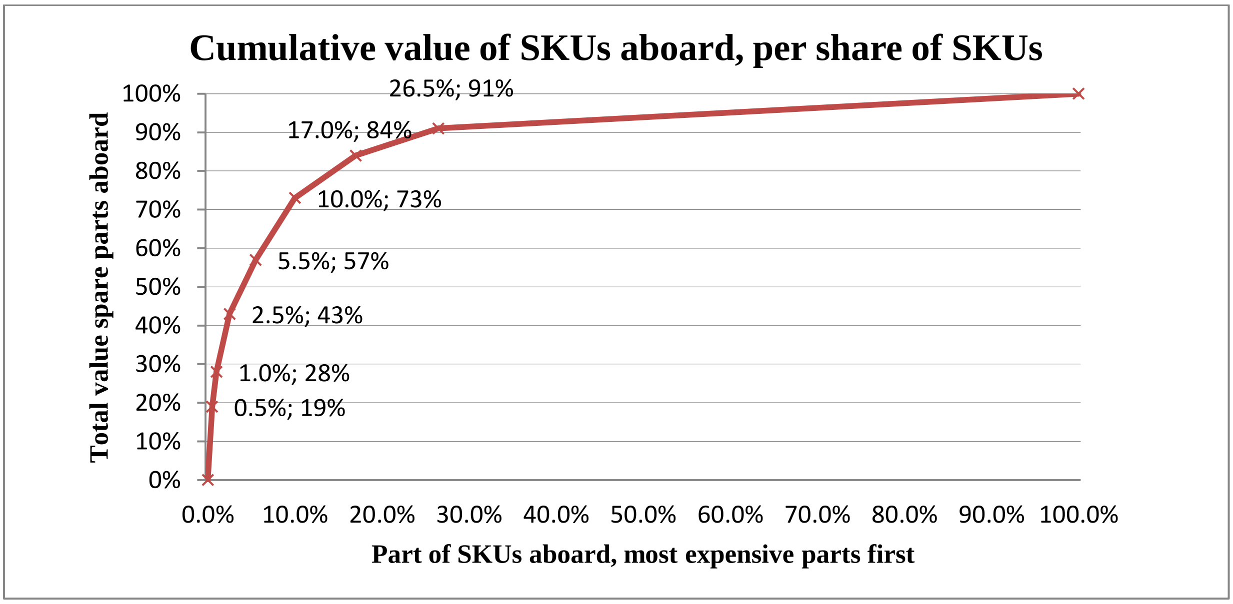

Figure 26 Cumulative stock value per part of SKUs

Figure 26 is based on the stock value per part of SKUs aboard the Fugro Brasilis, a FSSV. The total value is €381,000.

5.1.2 Usage of spare parts is unknown

Unfortunately, it is not possible to retrieve what spare parts have been used in the last couple of years. The administrative task is simply not conducted correctly. Besides, only spare parts that are purchased in the last couple of years have a value known in Star; the value of the spare parts which are put aboard at the first outfitting, which is the preparation of the new vessel for its first trip, is not easily accessible.

5.1.3 Spare parts for critical equipment will be equalised on the FSSVs

The four FSSVs currently have a different portfolio of stock, not because of optimisation to cope with the specific circumstances at the North Sea (Fugro Searcher, 2010 and Fugro Galaxy, 2011), the Atlantic Ocean near Brasil (Fugro Brasilis, 2013) or the Asia Pacific near Singapore (Fugro Equator, 2012), but due to a different criticality analysis of comparable equipment. The latter conducted analyses of the younger vessels are preferred and planned to be implemented to the Fugro Searcher and the Fugro Galaxy as well. Although the maintenance engineer has provided the recommended spare parts in the summer of 2013, the stocks at the vessels are not yet optimized in June 2014. As the VSI is responsible and does not have the spare parts high on his priority list, it is unclear how much time it is going to take to update the stock.

5.1.4 Approximation of the total recommended critical stock value

A lot of spare parts for critical equipment are currently not aboard or not registered as aboard, because the VSI does not feel the urge to remind the crew to order or register it properly. As the availability is high, the immediate necessity is not there to update the stock. Also the Fugro Brasilis lacks about 20% of the critical spare parts (165 stock keeping units of 850 critical SKUs). The ME department prescribes to store the items to enable the emergency repairs, as waiting for a spare part will cause a lot of downtime. Especially the cheaper parts should be aboard, as project time lost due to waiting on a cheap part has to be avoided. Table 11 shows that the Fugro Brasilis stores an approximated stock value of over €600,000. To put the value in perspective: considering the day rate of €35,000 to €70,000, the value is equal to roughly 10 days of waiting for a spare part delivery.

SKUs	Number SKUs	Value	Approximated value
Not aboard, value unknown	121		€ 126,500
Not aboard, value known	44	€ 46,000	
Most expensive	*3*	*€ 41,000*	
Less expensive	*41*	*€ 5,000*	
Total needed		€ 172,500	
Aboard, value known	868	€ 381,000	
Aboard, value unknown	125	-	€ 55,000
Approximated total value Stock aboard		**€ 608,500**	

Table 11 Approximation total critical stock value aboard a FSSV

Table 11 shows an overview of the estimated total recommended stock critical and non-critical value of stock aboard and required critical stock. The approximated value is over €600,000. Approximations of unknown purchase prices are made based on the average known purchase prices of SKUs.

There are in total 993 spare parts aboard of which 868 a purchase price is known. 715 of these 993 spare parts aboard are critical. Of 32 critical parts, there is less than the recommended stock aboard. Including these 32 critical parts, there are 165 critical spare parts missing.

Of 44 missing critical SKUs a price is known, and the costs to get these 44 SKUs at the recommended stock level is €46,000. Of these 44 SKUs 3 SKUs are responsible for €41,000. Based on the average price of the missing spare parts, it is expected that the correct level of critical spare parts will cost €172,500. However based on the variation of the prices of the 44 SKUs, the value to arrange the 150 SKUs is €20,000. The €20,000 is a reasonable price to limit the downtime due to waiting for spare parts of these relatively cheap SKUs.

5.1.5 Centralised stock – risk pooling

Current practises exclude centralised stock for all FSSVs. However, due to a couple of breakdowns last year the maintenance department initiated the plan to store large pieces of equipment on land. The goal of this stock is to buffer against long lead times of OEM in cases of failures of expensive equipment. The plan is that the OpCos of the FSSVs finance and share the stock. When one of the vessels needs a piece of the stored equipment, the OEM is contacted to replenish the stock. It depends on the equipment whether it is stored at the OEM or in a central warehouse. Whether this is the 3th party, has still to be arranged. As the different OpCos have to agree and approve the budgets, the orders are not yet placed at the suppliers.

5.1.6 Obsolescence & Last time buy

As stated there is no obsolete stock at the warehouse, as they only store and ship what is ordered by a vessel. As the vessels are expected to sail at least 25 years and the space aboard is limited, the obsolescence costs are not expected to be high.

Taking into account the current practice of individual stock management of the vessel and the limited long term relationship with suppliers, last time buys are not integrated in the FMS maintenance policy. When a last-time buy situation occurs, it will hopefully be announced and taken care of in consultation with the maintenance department.

Current practice at old vessels is to search for requested spares on the second hand market. Since 2006, FMS has only been once involved in a last time buy decision. That decision was made based on the expected vessel running hours left and the expected running hours per spare part.

5.2 Process of acquiring stock – explanation purchase process

This section is about the process of acquiring spare parts and tools to carry out the maintenance plan. Section 5.2.1 is about the purchasing process. Section 5.2.2 is about the organisation to handle emergencies.

5.2.1 The purchasing process

The following page shows the purchasing process at FMS. Purchases are ordered at the supplier by the purchasing department when the vessel's purchase order is approved by the Vessel Superintendent (VSI). The VSI is the responsible for the budget.

There are hardly any contracts with suppliers. The order depends on the service of the day and the delivery time discussed in the deal. Each two weeks the purchasing department checks for overdue deliveries and decides whether it's needed to take actions accordingly.

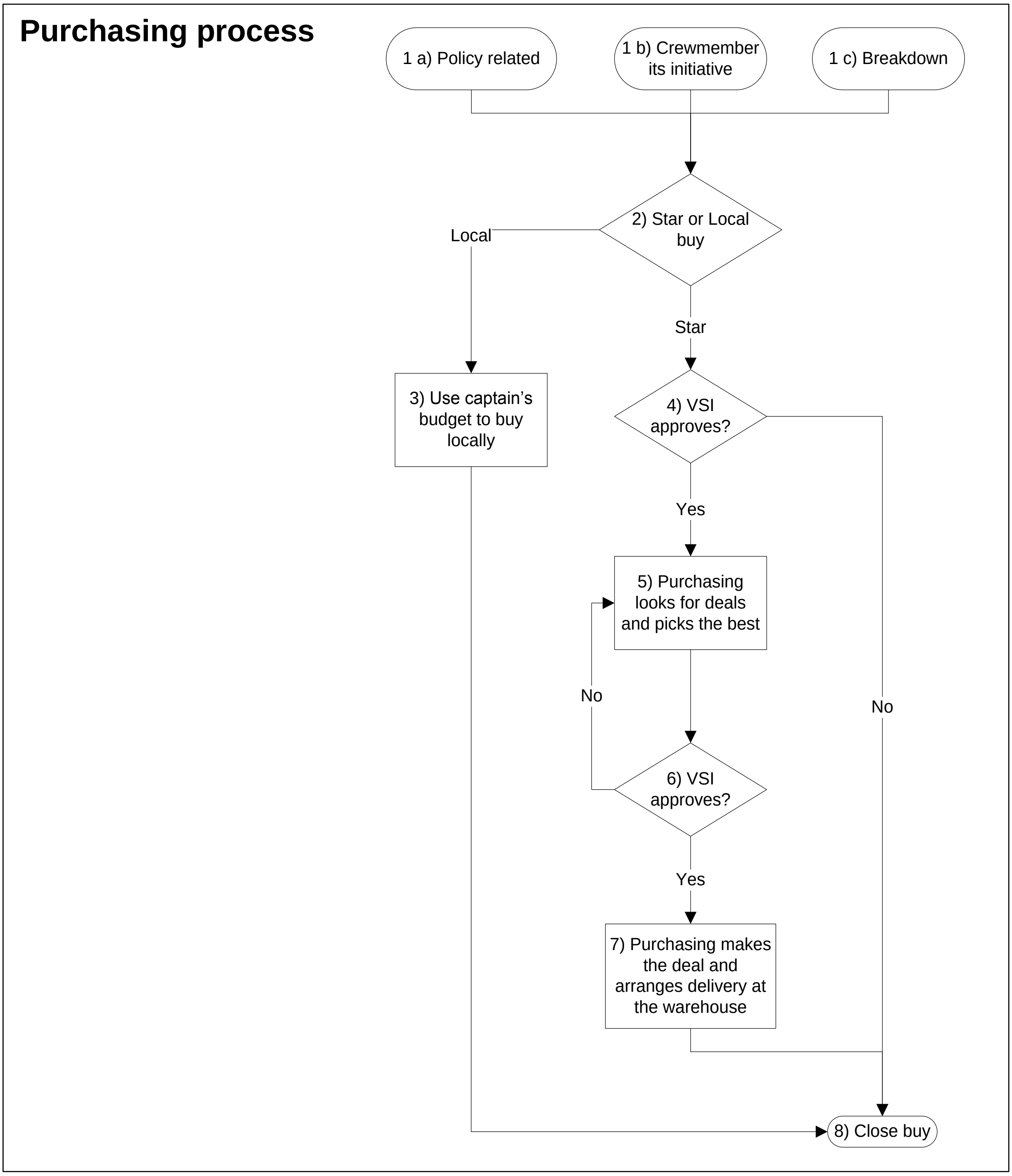

Figure 27 Overview purchasing process at FMS for a vessel

To get the proper equipment, spare parts and provisions aboard, there are different paths which could be taken as shown in Figure 27. A short explanation is given.

1) Reason of a buy

There are different reasons to arrange a shipment to the vessel. Reasons include the need of provisions, the running out of stock or policies that are changed. Policy related buys could be stock related, change of critical parts or QHSE prescriptions. Policy related buys could take a long time to be started (up to several months), as it needs reorganisation aboard, budget and all involved parties supporting the change.

2) Two main options

Most of the acquisitions are ordered via the preferred way, an order via Star. It is preferred, because it would not be the first time that a vessel is delayed because a crew member is missing due to shopping, besides crew members usually have other tasks to fulfil. Moreover, the buys via Star are registered and in the near future this information should be used to conclude contracts with suppliers. Maverick buying once there are contracts concluded is not a serious threat, as shopping for 60 persons for up to 4 weeks is a lot of work.

3) Local buy

The captain has a yearly budget and is responsible for this type of buys. The vessel could be in a port and some local available goods could be bought.

4) A buy via Star

Most of the equipment and provisions will be arranged via a purchase order in Star. First the budget holder, the VSI, decides whether the buy is approved. If not immediately, it could be approved some time later due to lower priority, or the crew will be told that an order is not going to be delivered. Due to the variation in importance of an order the time varies between 1 hour and a couple of weeks.

5) Purchasing department

After the approval of the VSI, the purchasing department will acquaint 3 quotations of different suppliers. This is usually acquainted within 3 days. According to the policy they have to do it for all orders, as there is a lack of contracts.

6) VSI approves purchase order

The VSI decides in consultation with the purchase department which quotation is promoted to an order.

7) Delivery to warehouse

Each two weeks all purchase orders are checked whether they are delayed. The delivery of the order at the warehouse means the end of the responsibilities of the purchasing department. The warehouse arranges the shipment to the proper port.

5.2.2 Capabilities of handling emergencies – bottleneck delivery time

The overall varying time to finish a purchase order varies from a few hours to several weeks. Emergency purchase orders can be handled really quickly, as the office is aware of the importance of the reduction of downtime. Another plus is that FMS has a small office; a VSI usually can easily contact and convince a purchaser of an emergency. Also, the suppliers involved in the oil industry are used to be flexible in their deliveries and services. However, in the case of spare parts, the needed resources have stored to be able to do a fast delivery.

The delivery time of suppliers is not known at FMS. Firstly, this is not asked and administered centrally and, secondly, some suppliers are not willing to go through their entire catalogue. The willingness to indicate important information like expected delivery times could be used as a supplier selection criterion.

5.3 Suppliers

To get an overview of suppliers the number of spare parts per supplier currently aboard is shown in Table 12. In total there are 61 suppliers of 992 items aboard, according to Star. The number of suppliers is excluding suppliers of provisions.

Items	Suppliers
1	21 suppliers deliver 1 item
2	11 suppliers deliver 2 items
3	3 suppliers deliver 3 items
4	4 suppliers deliver 4 items
5	1 suppliers deliver 5 items
6 to 10	5 suppliers deliver 6 to 10 items
11 to 20	7 suppliers deliver 11 to 15 items
21 to 30	2 suppliers deliver 21 to 30 items
31 to 50	4 suppliers deliver 31 to 50 items
52	1 suppliers delivers 52 items
157	1 suppliers delivers 157 items
362	1 suppliers delivers 362 items
992 items	61 suppliers in total deliver one or more items aboard of a FSSV

Table 12 The number of suppliers of the current stored spare parts at the FSSVs

Purchasing or the ME department should be capable to arrange long term contracts with the limited number of suppliers. Spare parts and maintenance services can be integrated in the contracts, as suppliers of spare parts are probably also involved with offering maintenance services.

6 Conclusions

This baseline study has identified details on the maintenance organisation of Fugro Marine Services. Despite the details, FMS' goal of becoming a preferred supplier in 2020 is not supported by quantitative measures. Currently the availability of the FSSVs is satisfying, but whether this is the result of proper management for a good price, is unknown.

The link between availability and vessel management is currently not quantifiable with current available data at FMS. Therefore the first conclusion is that FMS is currently not capable of showing being an economic interesting partner for vessel management services. Maintenance performance measurement is required.

The second conclusion is that the policy makers seem to have forgotten their clients' interest: providing an available vessel for a good price. Measuring efficiency or effectiveness of policies in terms of costs and availability is not part of the organisation. Of course, the policies have to be in place to keep the vessels in class, which is required to work off-shore. However, FMS is not the only vessel manager capable of keeping a vessel in class. The efficiency and effectiveness of the use of resources is currently not periodically assessed and consequently not optimised in any part of the organisation. Maintenance performance measurement is required.

The third conclusion is that the current use of the information system Star needs to be reassessed. Almost 15 people are involved with keeping Star supporting basic operations, including as well the employees of the M&RE department, as well as the employees officially working for the Star Support department. As long financial data is not integrated in Star, improvements are hard. This is the case, because the improvement supporting evaluations of the processes rely on the effect on costs and availability.

The fourth conclusion is that the M&RE department needs to be enforced. Maintenance is a key driver of high availability, but the fact that there is not even data for tactical decision making, while FMS is already founded in 2005, is alarming. One maintenance engineer for all policies and VSI support, and four employees mainly working on preparing Star for supporting daily operations, is very limited.

The fifth conclusion is that the performance measurement tool delivered by this research is supposed to play a vital role in proving the economic value of FMS, but highly depends on the quality of the information stored by the employees. The tool limited to providing an overview of the costs and availability of maintenance.

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Appendix III – Literature's performance indicators

The performance indicators might reveal that performance is good, but they do not show how to improve maintenance. They do not point to solutions, the ultimate indicators (Wireman, 2005, Pvii). Moreover all indicators together do not show whether maintenance is effective or efficient, the basis of performance measurement (Neely et al., 1995).

Overview performance objectives according to Van Horenbeek & Pintelon (2014) are displayed in Figure 28 and Figure 29.

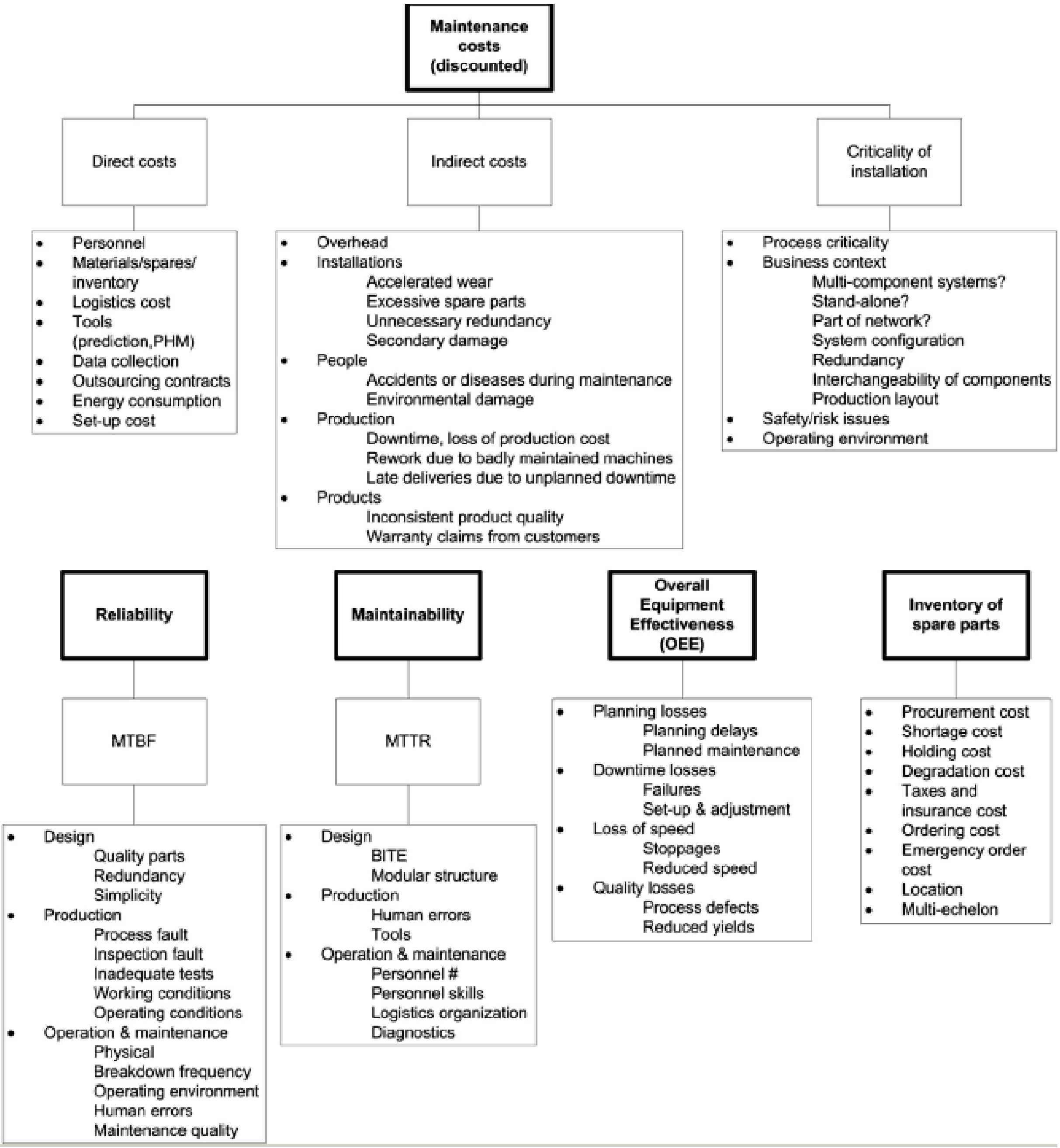

Figure 28 Set of tactical and operational maintenance performance objectives part 1

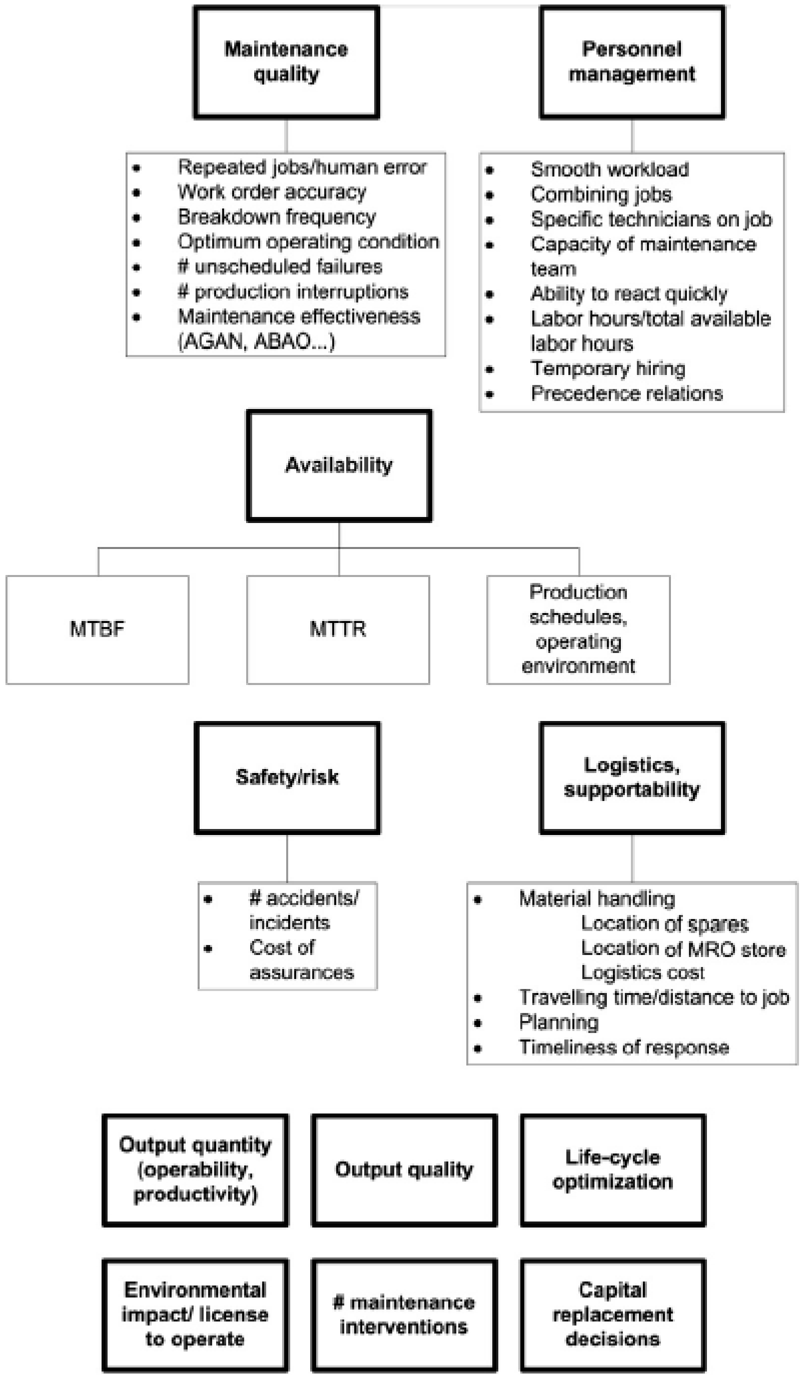

Figure 29 Set of tactical and operational maintenance performance objectives Part 2

Muchiri et al. (2011) have provided lists of common lagging and leading indicators in Table 13 and Table 14.

Category	Measures / Indicators	UNITS	Description	Recommended Targets
Work Identification	Percentage of Proactive work	%	Man-hours envisaged for proactive work/Total man hours available	75% - 80%
	Percentage of Reactive work	%	Man-hours used for reactive work/Total man-hours available	10% - 15%
	Percentage of Improvement work	%	Man-hours used for improvement & modification/Total man-hour available	5% - 10%
	Work request response rate	%	Work requests remaining in 'request' status for <5days/Total work requests	80% of requests
Work Planning	Planning Intensity/Rate	%	Planned work / Total work done	95% of all work orders
	Quality of planning	%	Percentage of work orders requiring rework due to planning/All WO	< 3% of all WO
	Planning Responsiveness	%	Percentage of WO in planning status for <5days/ All WO	> 80% of all WO
Work Scheduling	Scheduling Intensity	%	Scheduled man-hours/ Total available man-hours	> 80% of available man-hours
	Quality of scheduling	%	Percentage of WO with delayed execution due to material or man-power	< 2%
	Schedule realization rate	%	WO with scheduled date earlier or equal to late finish date/All WO	> 95% of all WO
Work Execution	Schedule Compliance	%	Percentage of wok orders completed in scheduled period before late finish date	>90%
	Mean Time To Repair (MTTR)	Hours	Total Downtime/No. of failures	
	Manpower Utilization rate	%	Total Hours spent on tasks / Available Hours	> 80%
	Manpower Efficiency	%	Time Allocated to Tasks/Time spent on tasks	
	Work order turnover	%	No. of completed tasks/ No. of received tasks	
	Backlog size	%	No. of overdue tasks/ No. of received tasks	
	Quality of Execution(Rework)	%	Percentage of maintenance work requiring rework	< 3%

Table 13 A summary of leading performance indicators for maintenance process

CATEGORY	MEASURES / INDICATORS	UNITS	DESCRIPTION
Measures of Equipment Performance	No. of Failures	No.	No. of Failures classified by their consequences: Operational, Non-operational, safety etc
	Failure / Breakdown Frequency	No./ Unit Time	No. of failures per unit time (A measure of Reliability)
	MTBF	Hours	Mean Time Between Failure (A measure of Reliability)
	Availability	%	MTBF/(MTBF + MTTR) = Uptime/(Uptime + downtime)
	OEE	%	Availability * Performance Rate * Quality rate
Measures of Cost Performance	Direct Maintenance Cost	$	Total corrective and Preventive Maint. cost
	Breakdown Severity	%	Breakdown cost / Direct Maint. Cost
	Maintenance Intensity	$ / Unit production	% of Maint. Cost per unit of products produced in a period
	% Maint. Cost component over Manufacturing cost	%	% Maint. Cost / Total Manufacturing cost
	ERV (Equipment Replacement Value)	%	Maint. Cost / New condition Value
	Maintenance Stock turnover	No.	Ratio of cost of materials used from stock within a period
	Percentage Cost of Personnel	%	Staff Cost / Total Maintenance Cost
	Percentage Cost of subcontractors	%	Expenditure of Subcontracting / Total Maintenance cost
	Percentage cost of Supplies	%	Cost of Supplies / Total Maintenance Cost

Table 14 A summary of lagging maintenance performance indicators

Appendix IV – FMS details on job supporting resource per managerial decision area

We stick to the basic decision making based on the identification of solutions to fill gaps of carrying out the maintenance plan on a job level and calculations of total costs involved with job supporting resources. Nevertheless, we do suggestions for improvement projects that require further analyses, including implementing mathematical models.

This appendix discusses the information required to support FMS' managerial decision making. The appendix elaborates on the interpretation of the information.

Decisions managerial evaluation - preventive

Managerial decision area (MDA) 1 is related to causes of job delays:

MDA1) Preventive maintenance – job level

Per job supporting resource the following information is required to determine whether improvements of maintenance job supporting resource preparations are available:

- Spare parts, tools and external services: *availability at due date job,* when not available it is of interest what has been the *moment of purchase, expected delivery date* and *actual delivery date.* Our tool is currently limited to determining the actual delay of a resource (actual delivery date later than job due date). When there is a delay, the decision is to start an analysis why the job resource had been unavailable. Additional analyses could for example identify that the resource should have been ordered earlier or that the supplier is unreliable.

- Facilities (vessel status): the *minimum required vessel status* of the job cannot be changed as it is related to the maintainability of the equipment. The *actual vessel status* is of interest to check whether the right jobs are executed during a maintenance opportunity.

- Crew: avoiding future delays due to crew capacity requires insights in all the tasks carried out by the crew. A 'cheap' way to enlarge the possibility of available crew during maintenance opportunities during the maintenance window (earliest start date, and due date) is to enlarge the time between the start and due date of the job. The policy could be to work on maintenance jobs with specific minimum vessel statuses with varying maintenance windows. E.g. the vessel is expected to be less often 'alongside' than 'in operation', leading to an earliest start date of two months for 'alongside' and one week for 'in operation'. At FMS there is currently no earliest start date; the achievement of the schedule relies on the chief engineer aboard. Other planning methodologies could also be studied and implemented if the benefits exceed the efforts.

- Time: *expected* and *actual duration* of *maintenance opportunities*. When there is no maintenance opportunity during the maintenance window, the lack of the resource 'time' is a cause of the delay. The planning might need to be improved when delays are not related to the other job supporting resources.

Managerial decision two is related to the costs involved with the job supporting resource policy:

MDA2) Preventive maintenance – resource level

The DST needs to aggregate the costs per supporting resource. The following information is required to determine the costs of interest to improve:

- Spare parts, tools and external services: the *ordering & stock and usage costs* per job supporting resource. Firstly, the ordering and stock costs are currently not explicitly accounted for. Optimising the related ordering and stock costs requires an improvement project to the general policy of ordering and stock keeping. Mathematical models for spare parts and tools optimisation can be studied and implemented when expected to be economical. Secondly, as changing the prescribed spare parts requires a technical analysis, the possibilities of decreasing the usage costs of the job supporting resources are limited to improving collaboration with suppliers. Resulting contracts could be about service levels and prices.

- Facilities (vessel status): the *facility costs* are of interest when the period of a particular vessel status (e.g. anchorage, alongside, dry dock) is allocated to maintenance. Facility costs are not maintenance related when there is a maintenance opportunity.

- Crew: the yearly *crew costs* are fixed. Capacity decisions require insights in the *competences*, *duration* and *interval* per job and other tasks conducted by the maintenance crew members.

- Time: preventive maintenance is conducted during maintenance opportunities, *unplanned downtime* (insufficient maintenance opportunities) or *planned downtime* (particular vessel status for maintenance). Time during maintenance opportunities is free of charge for maintenance. Maintenance opportunities might be insufficient to finish a maintenance job, leading to downtime. The planned unavailability is also blocking valuable commercial project time. Therefore, the planned periods of preventive maintenance, like the dry docking period, might be planned during a season with relative many maintenance opportunities due to bad weather. This reduces the actual missed commercial project time. Research on planning and scheduling could be studied for dry docking periods.

Managerial evaluation - critical corrective maintenance

Managerial decision area (MDA) 3 is about reducing the preparation time by retrieving the former missing job supporting resource aboard:

MDA3) Corrective maintenance – job level

The DST calculates the time to retrieve the job supporting resource for each repair. When the supporting resource is the bottleneck, the value of the availability of the resource is the time compared to second longest time to retrieve resource. The information and improvements are discussed per job supporting resource:

- Spare parts and tools: the *time of diagnosis to availability spare parts* and *tools* is required. The spare parts could be stored aboard to prevent future delays of a similar breakdown. When a tool is bought, the tool is aboard for future repairs. When the tool is rented, the decision could be to buy the tool. As inventory is costly and space is limited, it is not possible to keep everything aboard. Collaboration with the involved supplier could be intensified to reduce the time to acquire the non-available resources aboard in the future.

- Facilities (vessel status): the *minimum vessel status* cannot be changed. The required vessel status determines the minimum time to prepare the vessel when the vessel is at a commercial project site. When the minimum vessel status of the repair is ‘sailing’, the value of all resources aboard is highest.

- External services or Crew: the *time to external service engineer aboard* is required. Increasing the competences of the crew aboard to prevent the need of external services might be very expensive when the repair requires specialist competences.

Collaboration with the involved supplier could be intensified to reduce the time to acquire the service engineer aboard.

- Time: when a critical repair occurs, the highest priority is to repair the failed equipment. The goal of MDA 3 is to reduce future downtime by above mentioned possibilities to decrease the time to acquire job supporting resources.

MDA 4 is about the general policies to organise the job supporting resources:

MDA4) Corrective maintenance – resource level

The DST shows the total costs and waiting time (related to costs of downtime) involved with the different job supporting resources. The following information and actions could be taken:

- Spare parts and tools: the *costs* and *waiting time for spare parts and tools* could be a trigger to change the policy. Generally, at FMS all vessels have their own spare parts aboard. Expensive and large (space is limited aboard) spare parts and tools have the potential for savings when stored on land.

- Facilities: improving any other job supporting resource should take into account *the minimum vessel status* of the repair, e.g. benefits of putting aboard resources are limited for jobs that require the vessel to be laid up in a dry dock.

- Crew and external service: the yearly crew costs are fixed. Capacity decisions require insights in the *competences*, *duration* and *interval* per maintenance job and other tasks conducted by the maintenance crew members.

- Time: the *total waiting time* for spare parts, tools and services minus parallel waiting time and waiting time of facilities indicate the total reduction time when all resources would have been aboard during the period of retrieving data.

Technical evaluation

Managerial decision area (MDA) 5 is related to the maintenance plan of each piece of equipment. The equipment's maintenance plan is the result of the technological possibilities and corresponding costs to deal with deterioration. Therefore, improving the maintenance plan requires a thorough analysis.

Managerial decision area five:

MDA5) Maintenance plan preventive and corrective maintenance – equipment level

Optimising the maintenance strategy requires information on *deterioration*, *starting* and *resulting* condition of equipment and corresponding *costs of all job supporting resources* of preventive and corrective jobs involved per piece of equipment.

Decent modelling of deterioration requires a sufficient amount of data. A lack of data on deterioration and job effectiveness is often the case when the installed base is limited. Collaboration with similar equipment owners or OEMs might be an opportunity to gather data to improve the maintenance strategy and maintenance plan. Literature provides different methodologies to select maintenance strategies (among others; Gits,1992; Coetzee, 1997, P47-51; Löfsten, 1999; Arunraj & Maiti, 2009).

Appendix V – Data FMS

Introduction
The data required includes details on jobs and job supporting resources. To enable improvements at the job level, all job supporting resources have to be linked to the job involved. In general, the more details included, the more details can be shown per job. For the DST we have organised the data gathering as follows:

- Table 15 – Critical corrective jobs
- Table 16 – Preventive and non-critical corrective jobs
- Table 17 – Spare parts
- Table 18 – Tools
- Table 19 – Crew
- Table 20 – External services
- Table 21 – Failures
- Table 22 – Maintenance opportunities

Per identified piece of data is marked with red when FMS does not register the specific type of data. As FMS strives to be able to do the preventive & corrective bottleneck analyses, close collaboration to the ‘Star’ developers is required to gather and extract the necessary data in a structured way.

When the decision is made to measure maintenance performance, the first step will be to make sure the appropriate data is gathered and properly taken out of the system.

Both the DST users and the ‘Star’ developers have to collaborate to make the MPM methodology working.

Maintenance jobs – critical – 17 pieces of data – 5 missing

Job ID	Creation date	Equipment ID	Failure ID	Minimal vessel status	Crew/external	Spare parts	Tools
CFSSV0001	15-1-2013	E0001	FFSSV001	Sailing	Crew	Yes	Yes

Job vessel circumstance	Time Vessel Ready	Start job	Finish job	Total crew hours	Total service hours
Anchoring	15-1-2013 16:00	16-1-2013 11:00	16-1-2013 15:00		

Service costs	Resulting condition equipment	Time continuing schedule
	Moderate	16-1-2013 20:00

Table 15 Data critical job

Maintenance jobs – regular maintenance job, non-critical: maintenance plan and non-critical deterioration – 19 pieces of data – 6 missing

Job ID	Creation date	Equipment ID	Non downtime Failure?	Begin date	Due date	Minimal vessel status	Crew/external	Spare parts	Tools
PFSSV0001	1-1-2013	E0001			1-2-2013 0:00	Project	Crew	No	No

Job vessel status	Maintenance opportunity	Start job	Starting condition	Finish job	Finishing condition
Sailing	No	23-1-2013 21:00	Good	23-1-2013 23:00	Good

Total crew hours	Total service hours	Service costs
2		

Table 16 Data preventive maintenance job

Job requirement: Spare parts – 7 pieces of data – 1 missing

Date of order	Spare ID	Job ID	Expected delivery date	Time & date aboard
12-1-2012	SP00803	CFSSV0001	23-1-2012	23-1-2012 10:00
Date used			**Costs of spare part**	
16-1-2013			€ 1.000,00	

Table 17 Data spare parts

Job requirement: Tools

At FMS there is no separate registration of tools. Tools might be handled as spare parts when bought and handled as external services when hired.

Job ID	Tool ID	Hire/ aboard/ buy	Date of order	Expected delivery date
n.a.	n.a.	n.a.	n.a.	n.a.
Time & date aboard	**Date used**	**Costs of buy/ hire**	**Delivery costs**	
n.a.	n.a.	n.a.	n.a.	

Table 18 Data tools

Job requirement: Crew – 5 pieces of data – 1 missing

Job ID	Crew member ID	Task ID	Start	End
CFSSV0001	CM001		16-1-2013 11:00	16-1-2013 12:30

Table 19 Data crew

Job requirement: Services – 8 pieces of data – 2 missing

Job ID	Service ID	Task ID	Date of order	Appointment	Time & date aboard
CFSSV0003	SE0005		3-3-2013	4-3-2013 12:00	4-3-2013 11:30
Starting time & date				**Finishing task Time & date**	
4-3-2013 12:00				5-3-2013 10:00	

Table 20 Data services

Failures – 8 pieces of data – 3 missing

Failures are not registered separately at Star. The type of jobs indicates whether the job is involved with corrective maintenance. Additional information as the moment of failure and the moment of diagnosis is required to make available when a corrective job is registered.

Failure ID	During Job	Equipment ID	Critical failure (downtime)	Time of failure
FFSSV001	No	E0001	Yes	15-1-2013 9:40
Time of diagnosis		**Type of job**		**Job ID**
15-1-2013 10:00		Sailing		CFSSV0001

Table 21 Data failures

Maintenance opportunities – 6 pieces of data – 1 missing
At FMS the vessel status is logged outside ‘Star’ in Excel per day. An intelligent way to create useful information on maintenance opportunities is required for:

- Estimating downtime due to lacking maintenance opportunity
- Bottleneck analyses preventive maintenance jobs

Opportunity ID	Type opportunity	Vessel Status	Start opportunity	Expected duration (days)	Ending opportunity

Table 22 Data maintenance opportunities

Additional data required for calculations
Not all costs are directly related to maintenance jobs.

Our DST does not integrate spare part inventory to enable the average stock value based on current stock values. The average stock values have to be inserted.

- The crew costs are approximated. Further research is recommended.

Downtime costs / day	€ 50,000.00
Average value critical stock	€ 500,000.00
Average value preventive stock	€ 10,000.00
Costs of stock	15%
Costs of maintenance crew	€ 200,000.00
Percentage preventive	75%

Appendix VI – Calculations

This appendix contains the calculations to carry out the performance measurement costs, downtime & delay analyses.

Introduction

Several analyses are required to support the managerial decision making. The calculations are discussed in four parts:

- A - Costs
- B - Downtime critical failures
- C - Bottleneck preparations repair critical failure
- D – Calculations bottleneck preventive maintenance schedule

An overview of the parameters & variables is shown at the start of each subsection.

Classification DST

The decision support tool indicates the costs per minimum vessel status and condition of the maintained equipment. These are of interest for both corrective and preventive maintenance as discussed as follows:

- Concerning corrective maintenance, the value of repair competences, tools and spare parts aboard is higher when a repair can be done sailing.
- Concerning preventive maintenance, the vessel stances “alongside” or “dry dock” maintenance opportunities occur less often, are involved with facility costs and are related to commercial downtime. The conducted jobs during such a maintenance opportunity should require these vessel stances as the minimum vessel stance.

The vessel stances are not shown in the calculations. The DST makes use of the registered minimal vessel statuses.

A - Calculations costs

Overview parameters and variables

CC_{crew}	= crew costs preventive maintenance
CC_{direct}	= direct costs preventive maintenance
$CC_{downtime}$	= downtime costs preventive maintenance
$CC_{inventory}$	= inventory costs preventive maintenance
$CC_{j,facilities}$	= costs of facilities for corrective maintenance
$CC_{j, services}$	= direct costs of services job j
$CC_{j, spares}$	= direct costs of spare parts job j
$CC_{j, tools}$	= direct costs of tools job j
CC_{total}	= costs corrective maintenance
CD_{total}	= total critical downtime
CD_j	= critical downtime repair job j
MO_j	= duration maintenance opportunity repair job j
PC_{crew}	= crew costs preventive maintenance
PC_{direct}	= direct costs preventive maintenance
$PC_{downtime}$	= downtime costs preventive maintenance
$PC_{facilities}$	= total costs of facilities preventive maintenance
$PC_{inventory}$	= inventory costs preventive maintenance
$PC_{j, services}$	= direct costs of services job j
$PC_{j, spares}$	= direct costs of spare parts job j
$PC_{j, tools}$	= direct costs of tools job j
$PC_{m, facilities}$	= facility costs of maintenance opportunity m
PC_{total}	= total costs preventive maintenance
PD_{total}	= total preventive downtime
PD_j	= preventive downtime when maintenance job j occupies the vessel longer than the maintenance opportunity lasts
PD_m	= preventive downtime – planned upfront, dedicated period of preventive maintenance m
R_{stock}	= rate yearly costs per €, percentage
TC_{total}	= total costs maintenance
V_c	= value corrective stock spare parts
V_p	= value preventive stock spare parts

Total costs

The total costs of maintenance are involved with preventive maintenance costs and corrective maintenance costs.

1. $TC_{total} = PC_{total} + CC_{total}$

Preventive maintenance costs

The total preventive maintenance costs consist of costs of inventory, crew, downtime, job specific requirements and facilities.

2. $PC_{total} = PC_{inventory} + PC_{crew} + PC_{downtime} + PC_{direct} + PC_{facilities}$

The inventory costs rely on the average value of the stock and the inventory cost rate.

3. $PC_{inventory} = V_p * R_{stock}$

A part of the crew is involved with maintenance. The total costs involved with maintenance depend on the ratio that the crew member is actually working on preventive maintenance.

4. $PC_{crew} = C_{cm} * R_{PM}$

Downtime costs due to preventive maintenance depend on the total downtime and the costs per time unit.

5. $PC_{downtime} = PD_{total} * R_{dailycosts}$

Downtime can be planned and unplanned. Example planned downtime: dry docking periods are planned upfront. Example unplanned downtime: unexpected delays might happen when the external services are delayed during the time the vessel is alongside during a crew change.

6. $PD_{total} = \sum_{all\ PM\ periods\ m} PD_m + \sum_{all\ jobs\ j} PD_j$

The direct costs include costs of used spare parts, tools and external services.

7. $PC_{direct} = \sum_{all\ jobs\ j}(PC_{j,spares} + PC_{j,tools} + PC_{j,services})$

The total costs of facilities consist of port and shipyard fees for the vessel status of a period of planned maintenance at the shipyard or port

8. $PC_{facilities} = \sum_{all\ MOs\ m} PC_{m,facilities}$

Corrective maintenance costs

The total corrective maintenance costs consist of costs of inventory, crew, downtime and job specific requirements. Potential costs of facilities are booked at the specific repair job.

9. $CC_{total} = CC_{inventory} + CC_{crew} + CC_{downtime} + CC_{direct}$

The costs of inventory for critical repairs rely on the average value of the stock and the inventory rate.

10. $CC_{inventory} = V_c * R_{stock}$

The crew costs can be calculated based on the costs of crewmembers and part of the time spent on critical repairs.

11. $CC_{crew} = C_{cm} * R_{CM}$

The costs of critical downtime depend on the total downtime and cost rate.

12. $CC_{downtime} = CD_{total} * R_{dailycosts}$

The total downtime that needs to be accounted for can be compensated by a maintenance opportunity during the failure. A critical failure/ repair could be accompanied by a maintenance opportunity like bad weather.

13. $CD_{total} = \sum_{all\ jobs\ j}(CD_j - MO_j)$

The costs of the repair job consist of costs for spare parts, tools, services and facilities.

14. $CC_{direct} = \sum_{all\ jobs\ j}(CC_{j,spares} + CC_{j,tools} + CC_{j,services} + CC_{j,facilities})$

B – Calculations downtime critical failures

Overview parameters and variables

$TContinue_r$ = Time continue commercial project after critical repair job r
$TContinue_{total}$ = Total time continuing schedule all jobs
$TDiagnosis_{total}$ = Total time failure to diagnosis
$TDiagnosis_r$ = Time of diagnosis failure repair job r
$TDowntime_{total}$ = Total downtime critical failures
$TFailure_r$ = Time of failure repair job r
$TFinishJ_r$ = Finishing time job r
$TJob_{total}$ = Total repair time all critical repair jobs
$TPreparation_{total}$ = Total preparation time jobs: diagnosis to start jobs
$TStartJ_r$ = Starting time job r

The potential downtime costs are high. Different stages in the repair are distinguished. The different stages are shown in formula 15.

$$15.\ TDowntime_{total} = TDiagnosis_{total} + TPreparation_{total} + TJob_{total} + TContinue_{total}$$

The time to diagnosis is the time that passed between the failure and the identification of the required repair job.

$$16.\ TDiagnosis_{total} = \sum_{all\ jobs\ r}(TDiagnosis_r - TFailure_r)$$

The preparation time is the time required to take care of all maintenance job requirements. The crew finished the preparation when they start the carrying out of the job.

$$17.\ TPreparation_{total} = \sum_{all\ jobs\ r}(TStartJ_r - TDiagnosis_r)$$

The total time of the job is the time that passes from the start of the job until the job is finished.

$$18.\ TJob_{total} = \sum_{all\ jobs\ r}(TFinishJ_r - TStartJ_r)$$

The time to continue the commercial project needs to be included. The vessel might be days of sailing away from the commercial project location to repair the vessel.

$$19.\ TContinue_{total} = \sum_{all\ jobs\ r}(TContinue_r - TFinishJ_r)$$

C – Calculations bottleneck preparations repair critical failure

Overview parameters and variables

BRequirement $_{total}$	= Number of times bottleneck (requirement = “Stance/ Spares/ Tools/ Services”)
$DServices_r$	= Delivery time services (services available for job) job r
$DSpares_r$	= Delivery time spare parts (spares available for job) job r
$DStance_r$	= Time vessel in the right status for job r
$DTools_r$	= Delivery time tools (tools available for job) job r
$TDiagnosis_r$	= Time diagnosis failure corresponding to job r
$TBRequirement_{total}$	= Total downtime caused by delivery one bottleneck (requirement = Stance/ Spares/ Tools/ Services)
$WServices_r$	= Waiting time delivery services job r
$WSpares_r$	= Waiting time spare part delivery job r
$WStance_r$	= Waiting time vessel ready job r
$WTools_r$	= Waiting time tool delivery job r
$WRequirement_r$	= Total waiting time job requirement

Decreasing the repair preparations is involved with resource allocation. Whether a different set of resources aboard would have improved the performance, is calculated next.

The waiting time for the required vessel status (dry dock, alongside, anchorage, sailing) also influences the time to continue the commercial project. When a failure occurs, the vessel is only minutes away from sailing stance, which makes the resources aboard most valuable in terms of decreasing downtime.

20. $WStance_r = \sum_{all\ repair jobs\ r} \max(DStance_r - TDiagnosis_r; 0)$

The spare parts are immediately available when aboard, otherwise the delivery time depends on the flexibility and speed of the supply chain (supplier/ warehouse / sister vessel)

21. $WSpares_r = \sum_{all\ repair jobs\ r} \max(DSpares_r - TDiagnosis_r; 0)$

The tools are immediately available when aboard, else the delivery time depends on the flexibility and speed of the supply chain (supplier/ warehouse/ sister vessel)

22. $WTools_r = \sum_{all\ repair jobs\ r} \max(DTools_r - TDiagnosis_r; 0)$

When the crew is unable to carry out the repair, external service engineers are required. The waiting time to get the service engineer aboard depends on the availability of capacity at the supplier.

23. $WServices_r = \sum_{all\ jobs\ r} \max(DServices_r - TDiagnosis_r; 0)$

The bottleneck requirements have first priority. The longest time to get the job requirement aboard is the bottleneck. When particular job requirements turn out to be often the bottleneck, the policy might need to be reassessed.

24. $B\text{Requirement}_{total} = \underset{all\ jobs}{count}(\max(WStance_r; WSpares_r; WTools_r; WServices_r) = W\text{Requirement}))$

for “requirement”: stance, spares, tools and services

The time that could be saved when one bottleneck per job requirement is solved is calculated in formula 25. The reduced waiting time depends on the second longest waiting time.

25. $TB\text{Requirement}_{total} = \sum_{all\ jobs\ r}(if\ \max(WStance_r; WSpares_r; WTools_r; WServices_r) = W\text{Requirement}_r (W\text{Requirement}_r - \text{submax}(WStance_r; WSpares_r; WTools_r; WServices_r)))$

for “requirement”: stance, spares, tools and services

D – Calculations bottleneck preventive maintenance schedule

Overview parameters and variables

DD_j	= due date job j
$DServices_j$	= delivery time services (service engineers aboard) job j
$DSpares_j$	= delivery time spares job j
$DTools_j$	= delivery time tools job j
FJ_j	= finish time job j
FMO_j	= finish time last maintenance opportunity for due date job j
LMO	= number of jobs with a lacking maintenance opportunity longer than 7 days before due date
LServices	= number of jobs with service men aboard later than due date
LSpares	= number of jobs with spare part delivery later than due date
LTools	= number of jobs with tool delivery later than due date

Delays of the preventive maintenance jobs are associated with a higher risk on failures. The amounts of lacking spare parts, tools and services at the due date are of interest. Unavailable job requirements at the due date identify a potential way to improve achieving the schedule.

The spare part delivery is late when the delivery date is later than the due date.

$$26.\ LSpares = \underset{all\ jobs\ j}{count}(DSpares_j > DD_j)$$

The tool delivery is late when the delivery date is later than the due date.

$$27.\ LTools = \underset{all\ jobs\ j}{count}(DTools_j > DD_j)$$

The service delivery is late when the appointment is later than the due date.

$$28.\ LServices = \underset{all\ jobs\ j}{count}(DServices_j > DD_j)$$

Analyses of maintenance opportunities identify the role of the due date in the decision to carry out maintenance. Some chief engineers might check maintenance jobs with a due date within the next month when a maintenance opportunity occurs. Others might only take into account a couple of days and perform other tasks when all jobs of the week are finished.

$$29.\ LMO = \underset{all\ jobs\ j}{count}\big(if\ FJ_j > DD_j\ then\ (DD_j - FMO_j > 7)\big)$$

Appendix VII – Dummy data

Data on the jobs and job supporting resources is required to calculate the effectiveness gaps and value of the efficiency projects. The following data on job and per job supporting resources has served as input for the DST, of which the results are discussed in Chapter 6.

- Table 23 - Preventive jobs
- Table 24 - Corrective jobs
- Table 25 - Services
- Table 26 - Spare parts

- Table 27 - Tools
- Table 28 - Maintenance opportunities
- Table 29 - Failures

The data structure of FMS will most likely be different than we have used to do our calculations. The resulting data will, clearly, determine the final range of decisions the MPM methodology can support. For details on information per managerial decision: see Appendix III.

The fit of the output of Star and the input of the DST is important to be able to use the DST on a regular effective manner. When a lot of manual proceedings are required to do one performance measurement, the performance measurement assessment of the fleet will take a lot of time.

- *Close collaboration between the 'Star' developers and the end-users of the DST is required.*

Job ID	Creation date	Equipment ID	Failure related?	Due date	Minimal vessel stance	Crew/ external	Spare parts	Tools	Job vessel stance	Maintenance opportunity	Start job	Starting condition	Finish job	Finishing condition	Crew hours	Service hours	Service costs
PFSSV0001	1-1-2013	E0001		1-2-2013 0:00	Operation	Crew	No	No	Operation	No	23-1-2013 21:00	Good	23-1-2013 23:00	Good	2		
PFSSV0002	1-1-2013	E0007		1-2-2013 0:00	Anchoring	Crew	Yes	Yes	Anchoring	Yes	23-1-2013 12:00	Moderate	23-1-2013 17:50	Good	6		
PFSSV0003	1-1-2013	E1100		1-2-2013 0:00	Operation	Crew	No	No	Operation	No	28-1-2013 10:00	Good	28-1-2013 14:00	Good	6		
PFSSV0004	1-1-2013	E0002		1-2-2013 0:00	Alongside	External	Yes	No	Alongside	Yes	20-2-2013 8:00	Moderate	20-2-2013 17:29	Good	3	20	€ 5,000.00
PFSSV0005	1-1-2013	E0005		1-3-2013 0:00	Sailing	Crew	Yes	Yes	Anchoring	Yes	3-3-2013 13:43	Good	3-3-2013 21:44	Good	8		
PFSSV0006	1-1-2013	E0007		1-3-2013 0:00	Sailing	Crew	Yes	No	Sailing	No	8-2-2013 8:55	Good	8-2-2013 10:25	Good	2		
PFSSV0007	1-1-2013	E9810		1-3-2013 0:00	Operation	Crew	Yes	Yes	Operation	No	20-2-2013 1:42	Good	20-2-2013 5:53	Good	4		
PFSSV0008	1-1-2013	E0007		1-3-2013 0:00	Operation	Crew	No	No	Operation	No	22-2-2013 7:57	Good	22-2-2013 10:04	Good	4		
PFSSV0009	1-1-2013	E0123		1-3-2013 0:00	Anchoring	External	Yes	Yes	Anchoring	Yes	10-2-2013 9:50	Moderate	10-2-2013 20:08	Good	1	16	€ 3,000.00
PFSSV0010	1-1-2013	E0124		1-3-2013 0:00	Alongside	Crew	Yes	No	Alongside	Yes	5-2-2013 0:31	Bad	6-2-2013 1:23	Moderate	25		
PFSSV0011	1-1-2013	E0125		1-3-2013 0:00	Anchoring	Crew	Yes	No	Anchoring	Yes	15-2-2013 23:14	Bad	16-2-2013 10:42	Bad	25		
PFSSV0012	1-1-2013	E0126		1-3-2013 0:00	Alongside	Crew	Yes	No	Alongside	Yes	1-3-2013 20:15	Good	2-3-2013 10:04	Good	5		
PFSSV0013	1-1-2013	E0127		1-3-2013 0:00	Anchoring	Crew	Yes	Yes	Anchoring	Yes	22-2-2013 16:56	Good	23-2-2013 5:22	Good	3		
PFSSV0014	1-1-2013	E0128		1-3-2013 0:00	Sailing	Crew	Yes	No	Sailing	No	1-3-2013 20:57	Good	1-3-2013 23:21	Good	5		
PFSSV0015	1-1-2013	E0129		1-3-2013 0:00	Sailing	Crew	Yes	No	Sailing	No	21-2-2013 21:21	Moderate	22-2-2013 0:50	Good	7		
PFSSV0016	1-1-2013	E0130		1-4-2013 0:00	Operation	Crew	Yes	No	Operation	No	1-4-2013 0:51	Moderate	1-4-2013 2:31	Good	1		
PFSSV0017	1-1-2013	E0001		1-4-2013 0:00	Operation	External	No	No	Alongside	Yes	1-3-2013 10:50	Good	2-3-2013 4:02	Good	2	26	€ 8,000.00
PFSSV0018	1-1-2013	E0002		1-4-2013 0:00	Anchoring	Crew	No	No	Anchoring	Yes	12-3-2013 18:38	Good	13-3-2013 6:06	Good	7		
PFSSV0019	1-1-2013	E0003		1-4-2013 0:00	Anchoring	Crew	Yes	No	Anchoring	Yes	7-3-2013 6:24	Bad	7-3-2013 12:42	Good	4		
PFSSV0020	1-1-2013	E0004		1-4-2013 0:00	Alongside	Crew	Yes	Yes	Alongside	Yes	20-3-2013 10:00	Good	21-3-2013 6:14	Good	20		
PFSSV0021	1-1-2013	E0005		1-4-2013 0:00	Sailing	Crew	No	No	Sailing	No	3-3-2013 1:55	Bad	3-3-2013 6:55	Good	2		
PFSSV0022	1-1-2013	E0006		1-4-2013 0:00	Sailing	Crew	Yes	No	Sailing	No	21-3-2013 9:10	Good	21-3-2013 11:33	Good	4		
PFSSV0023	1-1-2013	E0007		1-4-2013 0:00	Anchoring	Crew	Yes	Yes	Alongside	Yes	20-3-2013 12:02	Good	21-3-2013 3:42	Good	16		
PFSSV0024	1-1-2013	E0008		1-4-2013 0:00	Anchoring	Crew	Yes	No	Anchoring	Yes	14-4-2013 22:31	Bad	15-4-2013 8:38	Good	10		
PFSSV0025	1-1-2013	E0009		1-5-2013 0:00	Anchoring	Crew	Yes	No	Anchoring	Yes	15-4-2013 12:31	Moderate	16-4-2013 2:43	Good	21		
PFSSV0026	1-4-2013	E0010		1-5-2013 0:00	Anchoring	Crew	Yes	No	Alongside	Yes	28-4-2013 11:46	Bad	28-4-2013 19:35	Bad	2		
PFSSV0027	1-4-2013	E0073		1-5-2013 0:00	Anchoring	Crew	Yes	Yes	Anchoring	Yes	30-4-2013 13:02	Good	30-4-2013 19:45	Good	10		
PFSSV0028	1-4-2013	E0074		1-5-2013 0:00	Operation	Crew	No	No	Alongside	Yes	28-4-2013 17:28	Good	29-4-2013 13:33	Good	13		
PFSSV0029	1-4-2013	E0075		1-5-2013 0:00	Operation	Crew	Yes	No	Operation	No	29-4-2013 11:31	Good	29-4-2013 16:01	Good	4		
PFSSV0030	1-4-2013	E0076		1-5-2013 0:00	Sailing	External	Yes	No	Alongside	Yes	17-4-2013 8:00	Moderate	17-4-2013 14:00	Good	0	15	€ 3,500.00
PFSSV0031	1-4-2013	E0077		1-5-2013 0:00	Sailing	Crew	Yes	No	Sailing	No	21-4-2013 8:56	Good	21-4-2013 10:44	Good	4		
PFSSV0032	1-4-2013	E0078		1-5-2013 0:00	Anchoring	External	Yes	No	Alongside	Yes	17-4-2013 10:18	Bad	17-4-2013 16:28	Good	0	12	€ 2,000.00
PFSSV0033	1-4-2013	E0079		1-6-2013 0:00	Anchoring	Crew	Yes	Yes	Anchoring	Yes	2-6-2013 0:51	Bad	2-6-2013 10:48	Good	13		
PFSSV0034	1-4-2013	E0080		1-6-2013 0:00	Anchoring	Crew	Yes	No	Anchoring	Yes	1-6-2013 12:39	Bad	1-6-2013 21:56	Good	12		
PFSSV0035	1-4-2013	E0081		1-6-2013 0:00	Anchoring	Crew	Yes	No	Anchoring	Yes	2-6-2013 19:39	Moderate	3-6-2013 2:25	Good	13		
PFSSV0036	1-4-2013	E0082		1-6-2013 0:00	Alongside	External	Yes	Yes	Alongside	Yes	15-5-2013 10:00	Good	15-5-2013 15:24	Good	0	10	€ 4,000.00
PFSSV0037	1-4-2013	E0083		1-6-2013 0:00	Alongside	Crew	Yes	Yes	Alongside	Yes	12-6-2013 8:15	Moderate	13-6-2013 12:50	Bad	19		
PFSSV0038	1-4-2013	E0001		1-10-2013 0:00	Alongside	Crew	Yes	Yes	Alongside	Yes	7-11-2013 21:15	Moderate	8-11-2013 2:52	Good	12		
PFSSV0039	1-4-2013	E0002		1-7-2013 0:00	Operation	Crew	Yes	No	Operation	No	6-7-2013 0:47	Bad	6-7-2013 2:16	Bad	2		
PFSSV0040	1-4-2013	E0003		1-7-2013 0:00	Operation	Crew	Yes	No	Sailing	No	7-7-2013 10:37	Good	7-7-2013 12:50	Good	4		
PFSSV0041	1-4-2013	E0004		1-7-2013 0:00	Operation	Crew	No	No	Operation	No	4-7-2013 20:53	Good	5-7-2013 0:03	Good	1		
PFSSV0042	1-4-2013	E0005		1-8-2013 0:00	Operation	Crew	No	No	Operation	No	25-7-2013 8:36	Moderate	25-7-2013 13:23	Good	3		
PFSSV0043	1-4-2013	E0006		1-8-2013 0:00	Anchoring	Crew	Yes	No	Anchoring	Yes	10-7-2013 8:51	Good	10-7-2013 16:32	Good	13		
PFSSV0044	24-4-2013	E0089	Yes	1-6-2013 0:00	Sailing	External	Yes	No	Alongside	Yes	22-5-2013 9:17	Moderate	22-5-2013 19:22	Good	3	12	€ 3,000.00
PFSSV0045	12-5-2013	E0100	Yes	1-6-2013 0:00	Anchoring	Crew	Yes	No	Anchoring	Yes	15-5-2013 13:00	Bad	15-5-2013 21:28	Bad	17		
PFSSV0046	3-7-2013	E0050	Yes	1-8-2013 0:00	Sailing	Crew	Yes	No	Sailing	No	5-8-2013 2:17	Good	5-8-2013 9:23	Good	11		
PFSSV0047	13-7-2013	E0089	Yes	1-8-2013 0:00	Anchoring	Crew	Yes	Yes	Anchoring	Yes	7-8-2013 9:27	Bad	7-8-2013 16:10	Moderate	14		
PFSSV0048	23-10-2013	E1001	Yes	1-12-2013 0:00	Sailing	Crew	No	No	Sailing	No	7-12-2013 1:42	Good	7-12-2013 6:43	Good	5		
PFSSV0049	26-10-2013	E0509	Yes	1-12-2013 0:00	Anchoring	Crew	Yes	No	Alongside	Yes	27-11-2013 8:49	Good	27-11-2013 15:38	Good	7		
PFSSV0050	4-11-2013	E0004	Yes	1-12-2013 0:00	Anchoring	Crew	Yes	No	Anchoring	Yes	9-12-2013 6:56	Moderate	9-12-2013 18:45	Good	3		
PFSSV0051	10-10-2012	E0028		11-10-2013 0:00	Dry Dock	External	Yes	No	Dry Dock	Yes	1-10-2013 9:00	Bad	4-10-2013 11:00	Good	2	40	€ 10,000.00
PFSSV0052	10-10-2012	E0028		11-10-2013 0:00	dry dock	External	Yes	Yes	dry dock	Yes	3-10-2013 14:00	Good	5-10-2013 13:43	Good	3	20	€ 4,500.00
PFSSV0053	5-11-2012	E0074		11-10-2013 0:00	Dry dock	Crew	Yes	Yes	Dry dock	Yes	4-10-2013 8:00	Moderate	9-10-2013 10:00	Good	50		
PFSSV0054	10-11-2012	E0075		11-10-2013 0:00	Dry Dock	External	Yes	No	Dry Dock	Yes	5-10-2013 8:00	Moderate	6-10-2013 18:00	Good	2	20	€ 4,000.00
PFSSV0055	5-5-2013	E0076		11-10-2013 0:00	DRY DOCK	External	Yes	Yes	DRY DOCK	Yes	5-10-2013 9:00	Bad	7-10-2013 0:00	Moderate	2	20	€ 3,000.00

Table 23 Preventive jobs data DST

Job ID	Creation date	Equipment ID	Failure ID	Minimum vessel status	Crew/ external	Spare parts	Tools	Job vessel status	Time Vessel Ready	Start job	Finish job	Total service hours	Service costs	Condition equipment	Time continuing schedule	Maintenance opportunity?
CFSSV0001	15-1-2013	E0001	FFSSV001	Sailing	Crew	Yes	Yes	Anchoring	15-1-2013 16:00	16-1-2013 11:00	16-1-2013 15:00			Moderate	16-1-2013 20:00	No
CFSSV0002	31-1-2013	E0002	FFSSV002	Sailing	Crew	Yes	Yes	Sailing	1-2-2013 7:00	1-2-2013 7:00	1-2-2013 20:00			Good	2-2-2013 6:00	No
CFSSV0003	3-3-2013	E0001	FFSSV003	Anchoring	External	Yes	No	Anchoring	4-3-2013 5:00	4-3-2013 12:00	5-3-2013 16:00	32	€ 4,000.00	Good	5-3-2013 20:00	No
CFSSV0004	7-3-2013	E0004	FFSSV004	Sailing	External	Yes	Yes	Anchoring	7-3-2013 17:00	10-3-2013 9:00	10-3-2013 17:00	7	€ 1,200.00	Moderate	10-3-2013 23:00	No
CFSSV0005	29-5-2013	E0087	FFSSV007	Sailing	Crew	Yes	No	Sailing	29-5-2013 19:25	29-5-2013 19:30	29-5-2013 22:00			Good	29-5-2013 22:30	No
CFSSV0006	17-9-2013	E0003	FFSSV010	Anchoring	External	Yes	Yes	Anchoring	19-9-2013 13:45	19-9-2013 14:00	22-9-2013 16:00	30	€ 4,500.00	Good	22-9-2013 21:00	No
CFSSV0007	5-12-2013	E1000	FFSSV014	Anchoring	Crew	Yes	No	Anchoring	6-12-2013 12:00	18-12-2013 12:00	19-12-2013 18:00			Good	19-12-2013 18:00	Yes

Table 24 Critical corrective jobs data DST

Job ID	Service ID	Task ID	Date of order	Appointment	Time & date aboard	Starting time & date	Finishing time & date
CFSSV0003	SE0005		3-3-2013	4-3-2013 12:00	4-3-2013 11:30	4-3-2013 12:00	5-3-2013 10:00
CFSSV0004	SE0110		7-3-2013	10-3-2013 9:00	10-3-2013 9:30	10-3-2013 10:00	10-3-2013 17:00
CFSSV0006	SE0088		17-9-2013	20-9-2013 12:00	20-9-2013 12:00	20-9-2013 12:15	22-9-2013 16:00

Table 25 Critical corrective services DST

Date of order	Spare ID	Job ID	Expected delivery date	Time & date aboard	Date used	Costs of spare part
1-2-2011	SP00121	CFSSV0004		16-2-2011 0:00	10-3-2013	€ 8,000.00
1-2-2011	SP01033	CFSSV0005		16-2-2011 0:00	29-5-2013	€ 500.00
12-1-2012	SP00803	CFSSV0001	23-1-2012	23-1-2012 10:00	16-1-2013	€ 1,000.00
15-2-2012	SP00401	CFSSV0002	28-2-2012	28-2-2012 14:00	1-2-2013	€ 100.00
4-5-2012	SP01039	CFSSV0005	20-5-2012	20-5-2012 13:00	29-5-2013	€ 1,500.00
18-11-2012	SP07531	PFSSV0045	5-12-2013	5-12-2013 14:00	13-5-2013	€ 1,000.00
12-12-2012	SP00751	CFSSV0006	23-12-2012	23-12-2012 10:00	22-9-2013	€ 15,000.00
5-1-2013	SP00028	PFSSV0004	23-1-2013	23-1-2013 10:00	20-2-2013	€ 800.00
5-1-2013	SP00071	PFSSV0002	23-1-2013	23-1-2013 10:00	23-1-2013	€ 750.00
5-1-2013	SP00114	PFSSV0005	24-2-2013	20-2-2013 8:00	3-3-2013	€ 500.00
5-1-2013	SP00157	PFSSV0006	1-2-2013	23-1-2013 9:00	8-2-2013	€ 1,600.00
5-1-2013	SP00200	PFSSV0007	13-2-2013	23-1-2013	20-2-2013	€ 2,000.00
5-1-2013	SP00243	PFSSV0009	3-2-2013	23-1-2013	10-2-2013	€ 1,600.00
5-1-2013	SP00286	PFSSV0010	29-1-2013	23-1-2013	5-2-2013	€ 1,400.00
5-1-2013	SP00329	PFSSV0011	8-2-2013	23-1-2013	15-2-2013	€ 500.00
5-1-2013	SP00372	PFSSV0012	22-2-2013	20-2-2013	1-3-2013	€ 17,000.00
5-1-2013	SP00415	PFSSV0013	15-2-2013	23-1-2013	22-2-2013	€ 500.00
15-1-2013	SP00804	CFSSV0001	16-1-2013	16-1-2013 11:00	16-1-2013	€ 300.00
15-1-2013	SP00805	CFSSV0001	16-1-2013	16-1-2013 11:00	16-1-2013	€ 4,500.00
15-1-2013	SP00803	CFSSV0003	23-1-2013	23-1-2013 10:00	5-3-2013	€ 900.00
15-1-2013	SP23005	PFSSV0004	23-1-2013	23-1-2013 12:00	20-2-2013	€ 15,000.00
31-1-2013	SP00401		20-2-2013	20-2-2014 11:00		€ 100.00
4-2-2013	SP00013	PFSSV0014	22-2-2013	20-2-2013	1-3-2013	€ 1,300.00
4-2-2013	SP00123	PFSSV0015	14-2-2013	23-1-2013	21-2-2013	€ 500.00
4-2-2013	SP00233	PFSSV0016	25-3-2013	20-3-2013	1-4-2013	€ 1,000.00
4-2-2013	SP00343	PFSSV0019	28-2-2013	20-2-2013	7-3-2013	€ 500.00
4-2-2013	SP00453	PFSSV0020	13-3-2013	20-2-2013	20-3-2013	€ 600.00
4-2-2013	SP00563	PFSSV0022	14-3-2013	20-2-2013	21-3-2013	€ 1,600.00
4-2-2013	SP00673	PFSSV0023	13-3-2013	20-2-2013	20-3-2013	€ 1,000.00
4-2-2013	SP00783	PFSSV0024	7-4-2013	20-3-2013	14-4-2013	€ 1,200.00
4-2-2013	SP00893	PFSSV0025	8-4-2013	20-3-2013	15-4-2013	€ 500.00
3-3-2013	SP00803		20-3-2013	17-4-2013 0:00		€ 1,000.00

Date of order	Spare ID	Job ID	Expected delivery date	Time & date aboard	Date used	Costs of spare part
4-3-2013	SP00121		20-3-2013	20-3-2013 11:00		€ 8,500.00
1-4-2013	SP01010	PFSSV0026	21-4-2013	17-4-2013	28-4-2013	€ 1,700.00
1-4-2013	SP01150	PFSSV0027	23-4-2013	17-4-2013	30-4-2013	€ 600.00
1-4-2013	SP01290	PFSSV0029	22-4-2013	17-4-2013	29-4-2013	€ 200.00
1-4-2013	SP01430	PFSSV0030	10-4-2013	20-3-2013	17-4-2013	€ 1,300.00
1-4-2013	SP01570	PFSSV0031	14-4-2013	20-3-2013	21-4-2013	€ 1,900.00
1-4-2013	SP01710	PFSSV0032	10-4-2013	20-3-2013	17-4-2013	€ 1,400.00
1-4-2013	SP01850	PFSSV0033	26-5-2013	15-5-2013	2-6-2013	€ 1,000.00
1-5-2013	SP03434	PFSSV0034	25-5-2013	15-5-2013	1-6-2013	€ 1,000.00
1-5-2013	SP03312	PFSSV0035	26-5-2013	15-5-2013	2-6-2013	€ 100.00
1-5-2013	SP03190	PFSSV0036	8-5-2013	17-4-2013	15-5-2013	€ 1,900.00
1-5-2013	SP03068	PFSSV0037	5-6-2013	15-5-2013	12-6-2013	€ 1,300.00
13-5-2013	SP07531		12-6-2013	12-6-2013 13:00		€ 1,000.00
16-5-2013	SP02946	PFSSV0038	31-10-2013	30-10-2013	7-11-2013	€ 1,100.00
16-5-2013	SP02824	PFSSV0039	29-6-2013	12-6-2013	6-7-2013	€ 1,700.00
16-5-2013	SP02702	PFSSV0040	30-6-2013	12-6-2013	7-7-2013	€ 400.00
16-5-2013	SP02580	PFSSV0043	3-7-2013	12-6-2013	10-7-2013	€ 1,100.00
16-5-2013	SP02458	PFSSV0044	15-5-2013	15-5-2013	22-5-2013	€ 25,000.00
16-5-2013	SP02336	PFSSV0045	8-5-2013	17-4-2013	15-5-2013	€ 1,600.00
16-5-2013	SP02214	PFSSV0046	29-7-2013	10-7-2013	5-8-2013	€ 1,200.00
16-5-2013	SP02092	PFSSV0047	31-7-2013	10-7-2013	7-8-2013	€ 400.00
16-5-2013	SP01970	PFSSV0049	20-11-2013	30-10-2013	27-11-2013	€ 1,800.00
16-5-2013	SP01848	PFSSV0050	2-12-2013	27-11-2013	9-12-2013	€ 1,400.00
29-5-2013	SP01033		12-6-2013	12-6-2013 14:30		€ 500.00
29-5-2013	SP01039		12-6-2013	12-6-2013 14:30		€ 1,600.00
1-6-2013	SP11500	PFSSV0051	24-9-2013	4-9-2013	1-10-2013	€ 1,900.00
1-6-2013	SP11450	PFSSV0052	26-9-2013	4-9-2013	3-10-2013	€ 1,700.00
1-6-2013	SP08743	PFSSV0053	27-9-2013	4-9-2013	4-10-2013	€ 1,700.00
1-6-2013	SP06036	PFSSV0054	28-9-2013	4-9-2013	5-10-2013	€ 1,500.00
1-6-2013	SP03329	PFSSV0055	28-9-2013	4-9-2013	5-10-2013	€ 100.00
17-9-2013	SP00751		2-10-2013	2-10-2013 10:00		€ 15,000.00
5-12-2013	SP02001	CFSSV0007	19-12-2013	19-12-2013 13:00	19-12-2013	€ 5,000.00

Table 26 Spare parts data DST

Job ID	Tool ID	Hire/ aboard/	Date of order	Expected delivery date	Time & date aboard	Date used	Costs of buy/ hire	Delivery costs
CFSSV0001	TL0010	Aboard				16-1-2013		
CFSSV0002	TL0512	Aboard				1-2-2013		
CFSSV0004	TL0003	Hire	7-3-2013	10-3-2013	10-3-2013 10:00	10-3-2013	€ 1,000.00	€ 100.00
CFSSV0006	TL0004	Hire	17-9-2013	20-9-2013	20-9-2013 13:00	22-9-2013	€ 1,500.00	€ 250.00
PFSSV0002	TL0018	Aboard				23-1-2013		
PFSSV0005	TL0023	Hire	4-1-2013	23-1-2013	23-1-2013	3-3-2013	€ 500.00	€ 100.00
PFSSV0007	TL0028	Aboard				20-2-2013		
PFSSV0009	TL0033	Hire	4-1-2013	20-2-2013	20-2-2013	10-2-2013	€ 1,500.00	
PFSSV0013	TL0038	Aboard				22-2-2013		
PFSSV0020	TL0043	Buy	4-1-2013	20-2-2013	20-2-2013	20-3-2013	€ 25,000.00	€ 250.00
PFSSV0023	TL0048	Aboard				20-3-2013		
PFSSV0027	TL1235	Aboard				30-4-2013		
PFSSV0033	TL1000	Buy	4-4-2013	20-3-2013	20-3-2013	2-6-2013	€ 10,000.00	
PFSSV0036	TL7650	Hire	4-4-2013	15-5-2013	15-5-2013	15-5-2013	€ 250.00	
PFSSV0037	TL5300	Aboard				12-6-2013		
PFSSV0038	TL2950	Aboard				7-11-2013		
PFSSV0047	TL6000	Hire	16-7-2013	10-7-2013	10-7-2013	7-8-2013	€ 1,000.00	€ 100.00
PFSSV0052	TL1750	Hire	1-6-2013	2-10-2013	2-10-2013	3-10-2013	€ 400.00	
PFSSV0053	TL4100	Aboard				4-10-2013		
PFSSV0055	TL6450	Aboard				5-10-2013		

Table 27 Tools data DST

M.O. ID	Type opportunity	Vessel Status	Start opportunity	Expected duration (days)	Ending opportunity	Costs facilities
MO0001	CrewChange	Alongside	23-1-2013 8:00	0.50	23-1-2013 14:00	
MO0021	WaitingWeather	Anchoring	23-1-2013 11:00	3.00	25-1-2013 23:12	
MO0017	WaitingWeather	Alongside	4-2-2013 0:31	4.00	6-2-2013 14:13	
MO0027	WaitingWeather	Anchoring	10-2-2013 4:15	1.00	11-2-2013 6:00	
MO0022	WaitingWeather	Anchoring	15-2-2013 21:00	1.00	16-2-2013 15:15	
MO0002	CrewChange	Alongside	20-2-2013 8:00	0.50	20-2-2013 18:00	
MO0023	WaitingWeather	Anchoring	22-2-2013 5:00	3.00	24-2-2013 13:00	
MO0018	WaitingWeather	Alongside	1-3-2013 20:00	2.00	3-3-2013 18:00	
MO0024	WaitingWeather	Anchoring	6-3-2013 17:41	2.00	8-3-2013 8:00	
MO0025	WaitingWeather	Anchoring	12-3-2013 17:00	1.00	14-3-2013 1:02	
MO0003	CrewChange	Alongside	20-3-2013 8:00	0.50	20-3-2013 19:00	
MO0026	WaitingWeather	Anchoring	14-4-2013 21:15	3.00	17-4-2013 6:00	
MO0004	CrewChange	Alongside	17-4-2013 8:00	0.50	17-4-2013 16:00	
MO0019	WaitingWeather	Alongside	28-4-2013 17:28	3.00	1-5-2013 9:15	
MO0028	WaitingWeather	Anchoring	5-5-2013 6:00	4.00	8-5-2013 11:49	
MO0005	CrewChange	Alongside	15-5-2013 8:00	0.50	15-5-2013 20:00	
MO0029	WaitingWeather	Anchoring	1-6-2013 15:35	2.00	3-6-2013 21:01	
MO0006	CrewChange	Alongside	12-6-2013 8:00	0.50	12-6-2013 18:00	
MO0030	WaitingWeather	Anchoring	1-7-2013 6:23	1.00	2-7-2013 10:15	
MO0007	CrewChange	Alongside	10-7-2013 8:00	0.50	11-7-2013 8:00	
MO0008	CrewChange	Alongside	7-8-2013 8:00	0.50	7-8-2013 18:00	
MO0009	CrewChange	Alongside	4-9-2013 8:00	0.50	4-9-2013 20:00	
MO0014	DryDock	Dry Dock	1-10-2013 12:00	10.00	11-10-2013 12:00	€ 10,000.00
MO0011	CrewChange	Alongside	30-10-2013 8:00	0.50	31-10-2013 6:00	
MO0016	AlongsidePM	Alongside	7-11-2013 21:00	1.00	8-11-2013 21:00	€ 500.00
MO0020	WaitingWeather	Alongside	24-11-2013 10:38	1.00	25-11-2013 7:00	
MO0012	CrewChange	Alongside	27-11-2013 8:00	0.50	27-11-2013 20:00	
MO0015	Breakdown	Alongside	8-12-2013 0:00	10.00	18-12-2013 12:00	€ 5,000.00
MO0013	CrewChange	Alongside	25-12-2013 8:00	0.50	27-12-2013 8:00	

Table 28 Maintenance opportunities (M.O.) data DST

Failure ID	During Job	Equipment ID	Critical failure (downtime)	Time of failure	Time of diagnosis	Type of job	Job ID
FFSSV001	No	E0001	Yes	15-1-2013 9:40	15-1-2013 10:00	Sailing	CFSSV0001
FFSSV002	No	E0002	Yes	31-1-2013 13:15	1-2-2013 7:00	Anchoring	CFSSV0002
FFSSV003	No	E0001	Yes	3-3-2013 23:10	3-3-2013 23:30	Anchoring	CFSSV0003
FFSSV004	No	E0004	Yes	7-3-2013 10:00	7-3-2013 13:15	Sailing	CFSSV0004
FFSSV005	No	E0089	No	23-4-2013 16:54	24-4-2013 2:00	Dry dock	PFSSV0044
FFSSV006	Yes	E0100	No	12-5-2013 8:04	12-5-2013 9:10	Anchoring	PFSSV0045
FFSSV007	No	E0087	Yes	29-5-2013 19:04	29-5-2013 19:24	Sailing	CFSSV0005
FFSSV008	No	E0050	No	3-7-2013 4:52	3-7-2013 7:00	Sailing	PFSSV0046
FFSSV009	Yes	E0089	No	13-7-2013 13:00	13-7-2013 14:00	Anchoring	PFSSV0047
FFSSV010	No	E0003	Yes	17-9-2013 13:30	17-9-2013 13:45	Anchoring	CFSSV0006
FFSSV011	Yes	E1001	No	23-10-2013 6:51	23-10-2013 11:15	Sailing	PFSSV0048
FFSSV012	Yes	E0509	No	26-10-2013 15:10	26-10-2013 16:00	Anchoring	PFSSV0049
FFSSV013	Yes	E0004	No	4-11-2013 16:50	4-11-2013 16:55	Anchoring	PFSSV0050
FFSSV014	No	E1000	Yes	5-12-2013 12:01	5-12-2013 12:15	Anchoring	CFSSV0007

Table 29 Failures data DST

Appendix VIII – Implementation plan

Introduction – preliminary implementation

This appendix contains a general overview of the project to implement the MPM methodology. Important factors of current situation:

- Currently, higher management is not aware of the possibilities of the developed MPM tool.
- The time required to change ‘Star’ is not indicated by the ‘Star’ developers.
- The in-house ‘Star’ developers have their own long list of improvement projects

Without prioritisation of higher management the gathering of data and construction of reporting that can actually be used, is not expected to be operational in 2015.

This is a concept version which can function as a basis for the actual plan of implementation.

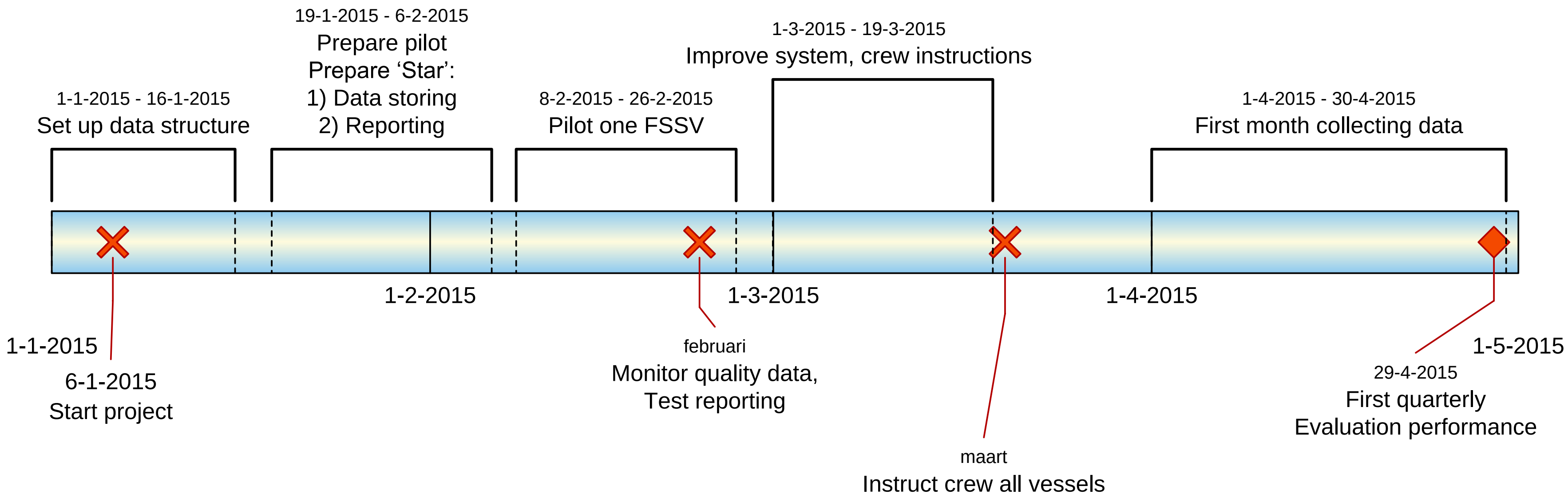

Figure 30 Implementation schedule Maintenance Performance Measurement project

Step 1) Simultaneously prepare information system and prepare pilot

The fit of the output of 'Star' and the input of the DST is important enable a regularly use of the DST. When a lot of manual proceedings are required to do one performance measurement, the performance measurement assessment of the fleet will take a lot of time.

Close collaboration between the 'Star' developers and the end-users of the DST is required.

To test the capabilities and difficulties in the data gathering and extracting to Excel sheets out of the information system, a pilot is recommended. The actual methodology of analysis could be automated as well. However, as the programming strongly relies on the resulting data-sheets, the programming is not delivered with this research.

The practical crew instructions depend on the resulting information system interface. The global steps are shown in Appendix V 'Data gathering plan'. The role of the crew in the success of performance measurement is important, as proper data is required for any improvement.

Role of the crew

There are two types of registrations: a maintenance job to solve a critical failure or a maintenance job that can be conducted while the vessel is in operation or during a maintenance opportunity.

The quality of input determines the quality of the output, so keeping the crew in touch and motivated requires attention. Feedback on the performance of maintenance is of interest to the crew. Together with the crew, that is supposed to carry out the maintenance plan, improvements of carrying out maintenance have to be discussed. Data is required for quantitative determination of resources, determining the economic value of FMS vessel management and optimising planning. However, the administrative burden on the crew is significant due to all different policies without any purposes of improving the organisation and should therefore be kept minimal. Data that is not used for any analysis is a waste of time and energy.

Step 3) Run pilot at one FSSV

To make sure the targeted analyses can be made, the information system and the data gathering process needs to be tested. The crew needs to work with a proper working system and a monthly period of checking should be sufficient to check whether all data is retrieved and accessible. The period of testing identifies whether there are a lot of difficulties to cope with. The planning of the implementation might need to be adjusted to enable the programmers to prepare the information system.

Step 4) Finish crew instructions

Based on the quality of the input during the pilot and feedback of the crew on the manual, the crew instructions have to be finalised before the system can be updated to implement the performance measurement in the fleet. A manual of using Star and Appendix V 'Data gathering plan' is suitable.

Step 5) Prepare start of data gathering vessels of interest

The crew needs to be instructed and the information system needs to be prepared before going live.

As the crew is already capable of using Star, the most important is to clearly describe the data required:

- The registration of hours worked on the job; large DDM jobs should be divided in separate tasks.

- Registration of unexpected maintenance (hours, spare parts) to solve deterioration
- Rigid prescription of the starting and resulting condition of equipment
- Registration of failures next to corrective maintenance jobs
- In & out of spare parts and usage per job
- Registration maintenance opportunities (expected duration "waiting for weather", port calls)

Step 6) Start data collection 1 April 2015

Step 7) Periodical evaluation

At first periods of evaluation the improvement possibilities are mainly for improving the organisation of both preventive and corrective maintenance. When the organisation of maintenance is excellent, but the total costs are still unsatisfying, an initiative can be started to improve the preventive maintenance schedule of a piece of equipment. However, the possibilities are limited by the design of the vessel and natural failure behaviour of the piece of equipment.

Performance measurement for improving maintenance

The constructed spreadsheet supports the managerial maintenance decision making by showing the costs and downtime details. The measures per maintenance job can be used to guide the improvement projects of specific tools, spare parts and maintenance service suppliers.

Performance measurement for clients

FMS is a non-profit service provider for the company Fugro. Non-profit is actually a bad name for FMS, as every euro saved increases the profit of the Fugro OpCos. FMS states that their quality of vessel management is exceeding the higher vessel management costs. In maintenance terms this could be supported by showing the effectiveness and efficiency of preventive and corrective measures, ultimately resulting in higher availability due to a better condition of equipment. Based on the maintenance performance measurement instrument the effectiveness and efficiency of maintenance can be analysed. The exact details of the report are outside the scope of this research. As there are vessel management companies collaborating with Fugro OpCos, competitors might already have a good reputation. These companies might be a good alternative when FMS is not capable of providing solid proof of good value for money.

Performance updates for crew

When evaluations are sent periodically to the involved crewmembers, they understand their effort administrating the information is valuable. As pointed out by the research, the right analyses depend on their interests concerning maintenance. The specification of the interests to motivate the crew is outside the scope of the research. However, all performance measurements depend on the quality of the data, so a motivated crew cannot be underestimated.

Appendix IX – Data gathering plan

This appendix contains two flowcharts. The flowcharts show when the data needs to be registered. The data needs to be registered when actions are taken.

One flowchart is about corrective maintenance “Flowchart: critical repairs”. The other is about preventive maintenance “Flowchart – regular maintenance: preventive maintenance plan and non-critical deterioration”.

The corrective flowchart starts at a failure, occurred during an operation or unexpected deterioration that is not causing critical downtime yet. When there is no downtime involved, the repair is handled like a preventive job.

The preventive flowchart starts at a job prescribed by the maintenance plan or deterioration that does not cause downtime.

Flowchart: critical repairs

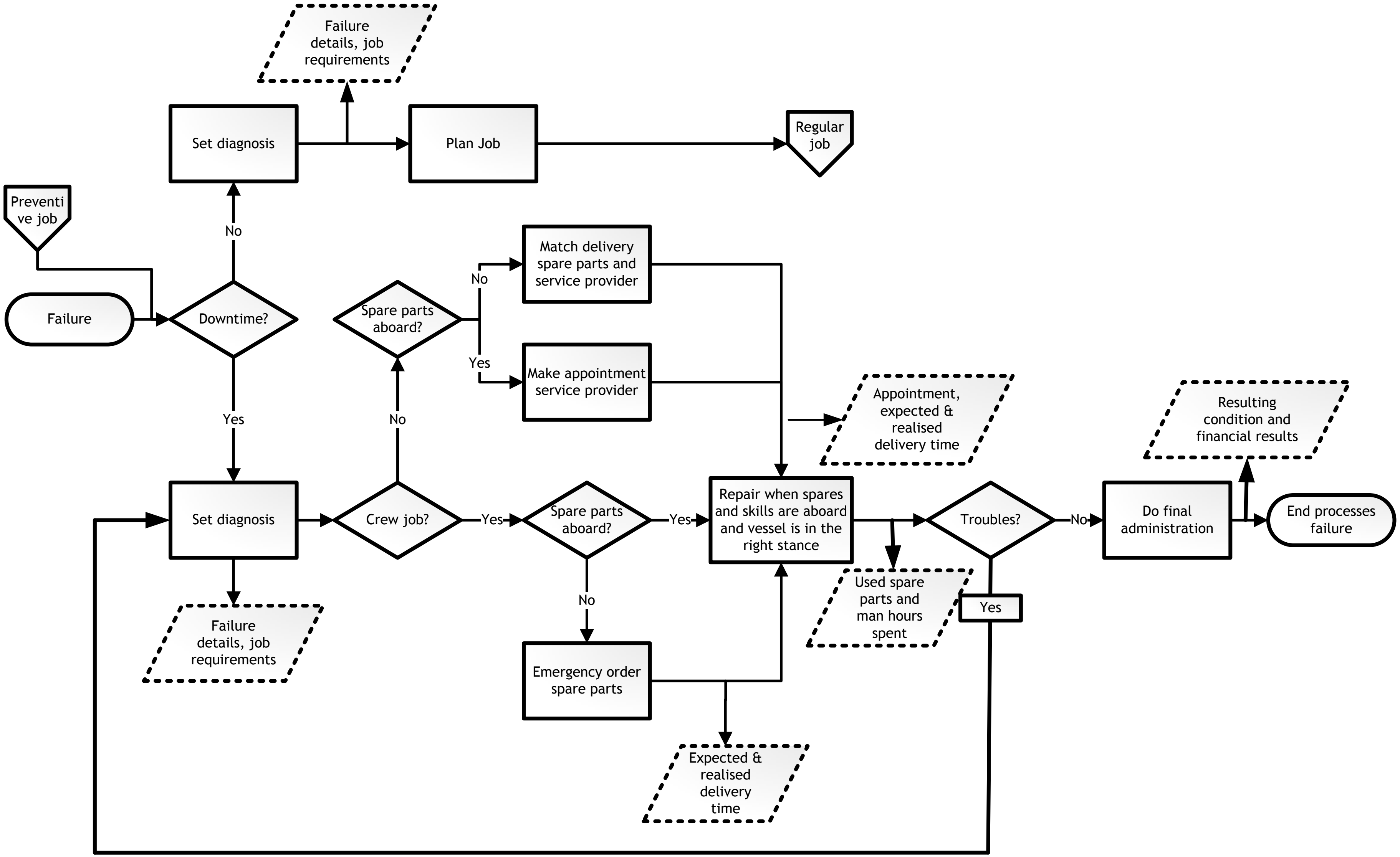

Figure 31 Flowchart to register information of critical repair job

Flowchart – regular maintenance: preventive maintenance plan and non-critical deterioration

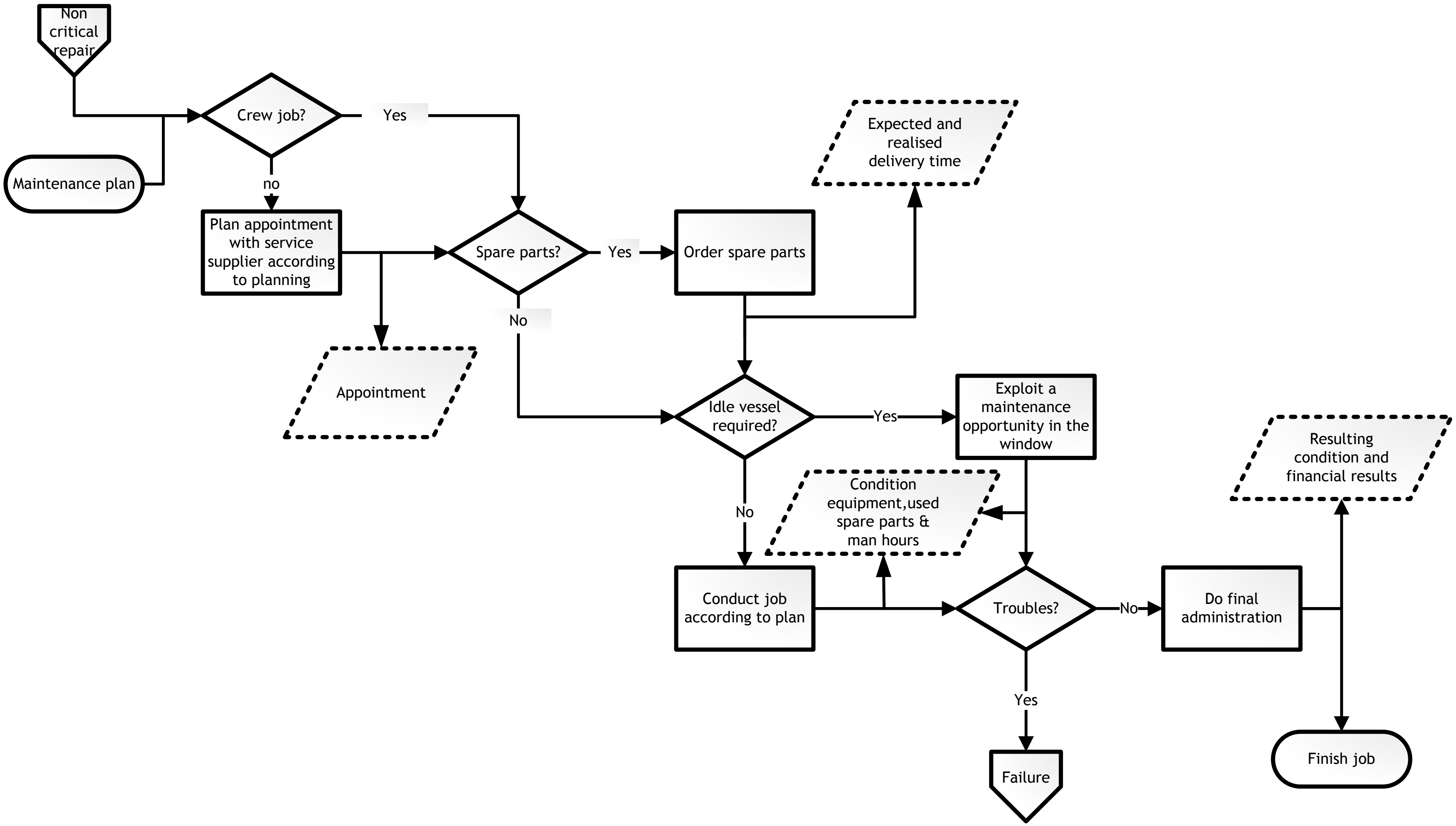

Figure 32 Flowchart to register information of regular maintenance jobs