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Master Thesis

Optimization of Dolphin Drillings Spare Part Management

Universitetet i Stavanger

By

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Abstract

The aim of this thesis is to analyze and improve Dolphin Drillings spare part management. That is done by conducting a current situation analysis, and proposing a framework for determining necessary spare part stock levels.

Chapter 3 presents a review of elements in an RCM analysis, and classification of spare parts. It is proposed to use the analytical hierarchy process to determine the importance of parameters influencing spare parts needs. Chapter 4 presents the current situation analysis of Dolphin Drillings spare part management. An important result of the current situation analysis is the overstocking tendency. For the current situation analysis and developing a framework for determining spare part stock levels, a Microsoft Access database was built. In chapter 5, the development of the database and framework is presented. The decision framework is divided in two parts. The first part consists of deciding if the spare part should be stocked, or purchased when required. The second part is determining stock levels. The framework resulted in potential savings of up to 46%. Chapter 6 presents the results of the proposed framework, by utilizing it to determine spare part stock levels for a selection of equipment. In chapter 7 results of the current situation analysis and development of the framework is presented and discussed.

Results of the current situation analysis include lacking information about materials in the computerized maintenance management system, incomplete and missing bill of materials, and overstocking. By addressing the proposed improvements Dolphin Drilling will in the future have a better maintenance and material management system as well as improved cost control. The proposed framework is based on comparisons of costs of stocking, and purchasing when required, and using relevant parameters such as consequence classification, redundancy, lead time, number identical parts installed, and expected consumption to determine spare part stock levels.

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Last but not least, I would like to thank my family and friends who have made my time at the University of Stavanger filled with knowledge, enthusiasm and good memories.

Abbreviation list

AHP – Analytical Hierarchy Process

BOM – Bill Of Materials

CM – Corrective Maintenance

CMMS – Computerized Maintenance Management System

DCT – Dolphin Classification Tool

DD – Dolphin Drilling

FMECA – Failure Modes, Effect and Criticality Analysis

FOE – Fred Olsen Energy

MODU – Mobile offshore drilling unit

MRP – Material Requirements Planning

MSI – Maintenance Significant Items

MSL – Maximum Stock Level

MTBF – Mean Time Between Failures

MTTF – Mean Time To Failure

NCS – Norwegian Continental Shelf

OEM – Original Equipment Manufacturer

OREDA – Offshore Reliability Data

PM – Preventive Maintenance

RCM – Reliability Centered Maintenance

ROP – Reorder Point

SAP – Systems, Applications & Products. DDs maintenance and material management system.

SCE – Safety Critical Element/Equipment

SFI – Senter for Forskningsdrevet Innovasjon, Norwegian Ship Research Institute.

UKCS – United Kingdom Continental Shelf

VED – Vital, Essential, Desirable

Definitions

To stock: This phrase means that a material should be purchased to storage.

Stock at failure: This phrase means that the material should be purchased when required.

BOMHeader: A BOMHeader material is the topmost material connected to a functional location or equipment. The BOM is connected to the BOMHeader.

BOMDetail: A BOMDetail material means that the material is part of a BOM.

Material: The word material is used as general term for spare parts, consumables, tools and construction materials.

Functional location: A functional location is the functional address of an asset, this is where the maintenance is performed and failures reported.

Framework: The framework is in this thesis referred to as the forms utilized in Microsoft Access for making decisions regarding stocking spare parts or not, determining spare part stock levels and finding overstock materials.

Access database: This is the Access database, containing all tables, queries and forms used to design the framework.

Table of contents

Abstract i

Acknowledgements ii

Abbreviation list iii

Definitions iv

Table of contents v

List of figures ix

List of tables xi

1 Introduction 1

1.1 Background 1

1.2 Objectives 2

1.3 Limitations 3

1.4 Methodology 4

2 About Dolphin Drilling 5

2.1 Fleet 6

2.2 Bolette Dolphin 6

2.3 SAP 6

2.3.1 Technical hierarchy 7

2.3.2 Consequence classification 9

3 Maintenance and spare parts theory 12

3.1 Reliability centered maintenance 13

3.2 Spare parts 20

3.2.1 Criticality classification of spare parts 22

3.2.2 Rules and regulations regarding spare parts 23

4 Current Situation Analysis 25

4.1 Distribution of materials 26

4.2 Distribution of inventory value 27

4.3 Overstocking 30
4.4 Duplicate materials 30
5 Development of spare part optimization methodology 31
5.1 Framework introduction 31
5.2 First decision: Stock or stock at failure 32
5.2.1 Costs of stocking at failure 33
5.2.2 Costs of stocking to storage 34
5.2.2.1 Holding costs 34
5.2.2.2 Procurement costs per purchase order 35
5.2.2.3 Logistics costs 35
5.3 Second decision: Deciding quantity to stock 36
5.3.1 Why are these parameters important? 36
5.3.2 Recommended stock level 37
5.4 Repair process 40
5.5 Failure process 40
5.5.1 Failure rate 41
5.5.2 Failure during lead time 43
5.6 Data acquirement 43
5.6.1 Explanation of attributes 44
5.6.2 Data not imported 47
5.6.3 Data export 49
5.7 Microsoft Access - Building the database 52
5.7.1 Tables in Access 52
5.7.2 Queries in Access 55
5.7.2.1 qry_AppendShoppingCart 58
5.7.2.2 qry_AppendShoppingCartManual 58

5.7.2.3 qry_AppendOverstock_qtysort, qry_AppendOverstock_Valuesort, qry_AppendOverstock_All ... 58
5.7.2.4 qry_EmptyOverstockList ... 59
5.7.2.5 qry_FL_DecisionAid ... 59
5.7.2.6 qry_NoInstDetailMaterial and qry_NoInstHeaderMaterial ... 60
5.7.2.7 qry_Overstock_FLsorted ... 60
5.7.2.8 qry_OverstockValue ... 61
5.7.2.9 qry_OverstockValueTotal ... 61
5.7.2.10 qry_ShowBOM ... 61
5.7.2.11 qry_ValueofBOM ... 61
5.7.2.12 qry_UpdateQtyShoppingCart ... 62
5.7.2.13 qry_ShoppingCart_vs_ActualStock ... 62
5.7.3 Forms in Access ... 62
5.7.3.1 Frm_DecisionAid ... 63
5.7.3.2 Frm_DecideSpareQuantity ... 68
5.7.3.3 Frm_DecideSpareQuantityManual ... 70
5.7.3.4 Frm_Overstock and frm_Overstocksubform ... 71
5.7.4 Macros in Access ... 72
5.8 Results of the framework ... 73
6 Examples showing framework results ... 75
6.1 Choke and kill manifold, valve 1. ... 76
6.2 Air compressor ... 78
6.3 Smoke and gas detectors ... 80
6.4 Overstock ... 80
6.5 Mud pump ... 82
6.6 Summary of examples ... 86
7 Results and discussion ... 87

7.1 Framework ... 87
7.2 Results from the current situation analysis ... 89
7.2.1 Incomplete material information ... 89
7.2.2 Number of repairs are not tracked ... 90
7.2.3 Overstocking ... 90
7.2.4 Spare parts not in technical hierarchy ... 91
7.3 Consequences of not having spare available ... 92
7.4 Equations/parameters ... 92
7.5 How to implement the framework ... 94
7.6 Data quality ... 94
7.6.1 Data format ... 96
7.7 Further work with framework ... 96
8 Conclusion ... 98
9 References ... 99
10 Appendices ... 101
Appendix A – SFI groups ... 101
Appendix B – Walkthrough of frm_DecisionAid ... 103
Appendix C – Walkthrough of frm_DecideSpareQuantity ... 107
Appendix D – Design of all queries ... 109
Appendix E - Database with framework ... 122

List of figures

Figure 2-1: Current fleet contract status. 6
Figure 2-2 SFI coding system. 8
Figure 2-3: Technical hierarchy of Bolette Dolphin 8
Figure 2-4: Draw works & machinery hierarchy 9
Figure 2-5: Hierarchy down to material and description. 9
Figure 2-6 Consequence classification as shown in SAP 10
Figure 2-7: Consequence classification matrix from DCT 11
Figure 2-8: ABC indicator, as used in SAP 11
Figure 3-1 Maintenance in a time perspective 12
Figure 4-1: Value of spare part inventory in percent. 26
Figure 4-2 This figure shows the value of spare parts connected to each SFI 28
Figure 4-3 Example of overstocked materials from Microsoft access database 30
Figure 5-1 Balance between inventory cost and total cost. 31
Figure 5-2 Analytical hierarchy process 38
Figure 5-3 Pairwise comparison , ... 38
Figure 5-4 Bath-tub curve. 40
Figure 5-5 Failure and reliability probability distribution. 42
Figure 5-6: ABC indicator, as used in SAP 47
Figure 5-7 Area code, screenshot from SAP 47
Figure 5-8 SE16N frontpage 50
Figure 5-9 Results of SE16N transaction 50
Figure 5-10 Design of the “tbl_Material” table 53
Figure 5-11 Datasheet view of “tbl_material” table 53
Figure 5-12 Relationships between tables in database. 54
Figure 5-13 Design view of "qry_ShowBOM" query 56
Figure 5-14 Result of "qry_ShowBOM" query 57
Figure 5-15 Design view of "qry_FL_DecisionAid" 59
Figure 5-16 Design view of “qry_NoInstDetailMaterial” 60
Figure 5-17 Datasheet view of "qry_overstock_FLsorted" query. 60
Figure 5-18 Design view of qry_overstockValue 61
Figure 5-19 Datasheet view of query “qry_ShowBOM”. 61
Figure 5-20 Datasheet view of query “qry_ValueofBOM” 62

Figure 5-21 Datasheetview of "qry_ShoppingCart_vs_ActualStock" 62
Figure 5-22 Form view of "frm_DecisionAid" 64
Figure 5-23 Complete DecisionAid form.. 68
Figure 5-24 Layout view of frm_DecideSpareQuantity.. 69
Figure 5-25 Filled out form 70
Figure 5-26 Form view of "frm_Overstock" 72
Figure 5-27 Macros 73
Figure 5-28 Macro from "frm_decideSpareQuantity" 73
Figure 7-1 CS15 SAP transaction 91
Figure B-1 Form view of “frm_DecisionAid” 103
Figure B-2 Filtered results.. 103
Figure B-3 Automatic retrieved data after selecting functional location. 104
Figure B-4 Drop-down list of associated spare parts 104
Figure B-5 Filled out form 105
Figure C-1 Blank “frm_DecideSpareQuantity” form 107
Figure C-2 Choosing material from dropdown list. 107
Figure C-3 Almost complete “frm_DecideSpareQuantity” form.. 108
Figure D-1 Design view of query qry_AppendOverstock_All 109
Figure D-2 Design view of query “qry_AppendOverstock_qtysort”................................... 110
Figure D-3 Design view of query “qry_AppendOverstock_valuesort” 111
Figure D-4 Design view of query “qry_AppendShoppingCartt” 111
Figure D-5 Design view of query “qry_AppendShoppingCartManual”.............................. 112
Figure D-6 Design view of query “qry_EmptyOverstockList”... 112
Figure D-7 Design view of query "qry_FL_DecisionAid" 113
Figure D-8 Design view of query “qry_No_InstDetailMaterial”... 114
Figure D-9 Design view of query “qry_No_InstHeaderMaterial” 115
Figure D-10 Design view of query “qry_OverstockFLsorted" 116
Figure D-11 Design view of query “qry_OverstockValue" 117
Figure D-12 Design view of query “qry_OverstockValueTotal"... 118
Figure D-13 Design view of query “qry_ShoppingCart_vs_actualstock" 118
Figure D-14 Design view of query “qry_ValueofBOM" 119
Figure D-15 Design view of query “qry_ShowBOM".. 120
Figure D-16 Design view of query “qry_UpdateQtyShoppingCart" 121

List of tables

Table 3-1 Rausands (1996) proposed FFA sheet 14
Table 3-2 FMECA worksheet proposed by Rausand (1996) 15
Table 3-3: Dolphin Drilling's categorization of materials. 21
Table 4-1: Value of inventory 25
Table 4-2: Distribution of materials with price>0. 26
Table 4-3 All materials 26
Table 4-4 Inventory value sorted by material types 27
Table 4-5 Inventory value sorted by MRP type 27
Table 4-6 ZSPR materials sorted by MRP type 27
Table 5-1 Weightage of spare part classification parameters. 39
Table 5-2 Data required to build database in Microsoft Access 44
Table 6-1 A selection of equipment used to show the results of the framework. 75
Table 6-2 Recommended spare parts for the kill and choke valve 77
Table 6-3 Recommended spare parts for the air compressor 79
Table 6-4 Smoke and gas detectors 80
Table 6-5 Recommended spare part stock levels, for materials currently overstocked 81
Table 6-6 Recommended spare parts for mud pump 85

1 Introduction

In this thesis Dolphin Drillings (DD) spare part management is analyzed. In connection with the analysis a framework for deciding which spare parts that should be stocked, as well as spare part stock levels is presented. In the framework a set of parameters that influence the need for spare parts are discussed, as well as comparing costs of having the spare part on hand and purchasing spare parts when required/at failure. This framework was created to reduce costs of spare part inventories, while minimizing the risk of HSE incidents or operational downtime. The framework is easy to implement for the mobile offshore drilling units (MODUs) in DDs fleet which use SAP as their maintenance and spare part management system. In the thesis a Microsoft Access database is presented. The database includes all functional locations, equipment and materials used for Bolette Dolphin, one of DD MODUs. The database is based on exported data from SAP, which is DDs computerized maintenance management system (CMMS) for Bolette Dolphin. The database makes it possible to compare the frameworks recommended spare part stock levels, with the current stock levels. The current situation analysis and framework resulted in several improvement potentials for spare part management, as well as showing how to reduce the value of spare part inventory.

The disadvantage of operating MODUs compared to fixed installations is that the supply chain may vary from year to year based on the MODUs position. This means that onshore storage locations has to be developed to best serve the MODUs and account for potential location changes. Today DD operates MODUs around the world, but mainly on the NCS and UKCS from main offices in Aberdeen and Stavanger. As the supply/logistics conditions are quite good on the NCS and UKCS compared to remote areas such as Colombia or East Africa, the framework are valid for MODUs operating in this area, but can easily be modified to match conditions in other areas by changing the planning perspective, and weightage of parameters.

1.1 Background

The background for the thesis is improving the spare part management in DD. All organizations benefit of having a procedure for continuous improvement. This is also the case for DD.

By improving spare part strategy, costs attached to maintenance and operation can be reduced as spare part stock levels can be reduced. It is important not to reduce the stock levels to a point where rules and regulations are not fulfilled, or HSE incidents or operational downtime is risked. The total value of the spare part inventory is around $18 million, excluding the value of capital spares. By reducing the spare part inventory value, funds become available for other uses. When determining the spare part inventory there are several considerations to make. Mainly three departments are involved when deciding the budget for maintenance and spare parts, the financial, operational, and maintenance department. With the current market conditions it is important to turn every stone in order to reduce costs, therefore it is necessary to have a framework for deciding the optimal spare part inventory. With a clear framework it is possible to justify and document the necessity of the spare part inventory.

With cost efficient and productive operation and maintenance, DD will be able to provide the best tender when trying to win contracts.

1.2 Objectives

The objective of this thesis is to create a framework for determining which spare parts to stock and not stock for MODUs in Dolphin Drillings fleet. In maintenance and spare part management there are high costs. It is also potential for making cost reductions. By finding the optimal balance between which parts to stock, and which parts to purchase when needed, DD has the possibility to reduce their capital tied up in spare parts. A typical spare part inventory consists of approximately 25 000 – 30 000 unique items, stored either at a coast base, a supplier warehouse or on the MODU.

By creating a framework for spare part stocking, the framework may in the future be implemented as a part of the overall spare part strategy in DD. The framework will be based on recent research within inventory optimization, maintenance research and a set of criteria for the spare parts. Included in these criteria are the main equipment criticality classification, material cost, availability, consumption and more.

After the framework is outlined it will be used to determine the necessary spare parts for a selection of equipment. The results of the framework will then be compared to the current inventory, and an estimation of potential savings by using the framework will be presented.

1.3 Limitations

When working with the thesis some limitations were made in order to restrict the extent of the thesis.

As a requirement for analysis, the technical hierarchy of functional locations and materials has to correspond to the technical hierarchy described in section 2.3.1

Only materials from SAPs material management module is included in the database. Compared to the number of materials in SAP, there are very few items that are procured or used without having a material number in SAP.

Failure rates are assumed to be exponentially distributed, which is further explained in section 5.5, describing the failure process.

Repair time are assumed to be instantaneous which results in MTTF=MTBF. This influences the analysis of probability of available spare, and second failure when waiting for stock replenishment. The reason for this assumption, is that the lead time is often much longer than the actual repair time. The inclusion of repair times will not improve the framework noteworthy, as the lead time for materials is generally much larger than actual repair times. To demonstrate the difference; lead times is often measured in days or weeks, while repair time is measured in hours.

Supply and logistics conditions are assumed to be similar or equal to the conditions for supplying MODUs in the North Sea. This influences the weightage of parameters in the framework. The weightage of parameters should be reevaluated for the framework to be valid for MODUs operating in other areas than the North Sea. Due to the nature of MODU contracts, and logistics conditions in the North Sea a planning period of one year is assumed to be sufficient. This means that the recommended stock levels as a minimum should cover one year of operation and expected usage of spare parts.

Spare part management comprises many aspects, such as supply chain, storage, procurement and which spare parts to stock and stock levels. This thesis mainly focuses on the part regarding the procurement criteria and stock levels. In order to decide on where to store parts, NORSOK Z-008, annex C may be used. There a risk matrix for where to store spare parts is proposed. In this thesis it is assumed that DD has already adequate routines for storing spare parts.

1.4 Methodology

The literature studied for this thesis is based on scientific articles and publications written in the field of maintenance and spare part management. Research directly applicable to offshore drilling operations is scarce, therefore only elements of the studied literature are suitable for an organization performing offshore drilling operations.

Parameters influencing spare part needs have been discussed with maintenance management and material management personnel at Dolphin Drilling, by doing this the most important parameters have been included in the thesis.

Data regarding failure processes as well as failure rates have been collected from OREDA, which is a comprehensive reliability data handbook developed by a group of oil and gas companies, in cooperation with SINTEF.

In this thesis all data regarding material inventories, technical hierarchy is based on Bolette Dolphin. Information about DDs current situation, is based on discussions with onshore maintenance management and material management personnel, and exported data from DDs CMMS. The exported data have been used for designing an Access database, which enables manipulation of data to find key figures regarding the current situation analysis.

The development of the framework for determining spare part stock levels, have been done in Microsoft Access. In Access queries have been designed to retrieve selected data in a understandable format. This data is then displayed in forms. The development of each query is described in chapter 5. The development of the database was a more comprehensive task than assumed. It is consists of tables, queries and forms which has to be designed individually and connected by criteria, and relationships between tables. These relationships gives the database the same structure as the technical hierarchy as the drillship Bolette Dolphin.

As a practical example of determining spare part stock levels, the proposed framework has been utilized in order to compare results of the framework with the current situation analysis.

2 About Dolphin Drilling

The Dolphin Drilling companies form the drilling contracting business activities of Fred. Olsen Energy ASA. Dolphin Drilling owns and operates MODUs, and their fleet consists of both drilling rigs and drilling ships, as well as one accommodation rig. Their vision is “to be the preferred drilling contractor for the operation of mobile drilling units” (dolphindrilling.no, 2015).

Their offices in Aberdeen, Scotland; Stavanger, Norway and Pemba, Mozambique control the offshore operations around the world. Management and administrative support including employment of international offshore personnel are provided by the office in Singapore.

Dolphin Drilling is one of the longest established independent drilling contracting companies in the offshore arena tracing its roots back to the earliest offshore exploration activity in the North Sea in the mid nineteen sixties. The Fred Olsen family’s interest pre-dates this with a history in shipping activity stretching over 160 years.

In 1997 Dolphin Drilling were listed on the Oslo stock exchange under Fred Olsen Energy ASA, by doing this the offshore activities were brought together into a single entity. Since the listing Dolphin Drilling has expanded and increasingly focused on international arenas and moved into deep water activity.

Dolphin Drilling is a well-established name in offshore drilling. The company has operated in all the major offshore oil and gas provinces in the world. In recent years, they have operated in most of the major areas of offshore activity, including the North Sea, West and East Africa, Mediterranean, India, Brazil and Gulf of Mexico.

Dolphin Drilling’s core business values combine long-term thinking with the advantages of being an independent contractor with a streamlined management structure. This ensures that they are well positioned to respond rapidly and flexibly to customer needs whilst at the same time maintaining safe and efficient operations within their key business parameters. (dolphindrilling.no, 2015).

2.1 Fleet

The market has been rough the last year and many companies has had to lay off staff, and contracts are either terminated or not renewed as well as old rigs are being scrapped due to fewer contracts and the reduction of day rates globally. Dolphin Drilling's fleet status is shown in figure 2-1. At the end of 2015, three MODUs are without contracts. This is due to the difficult market conditions at the moment.

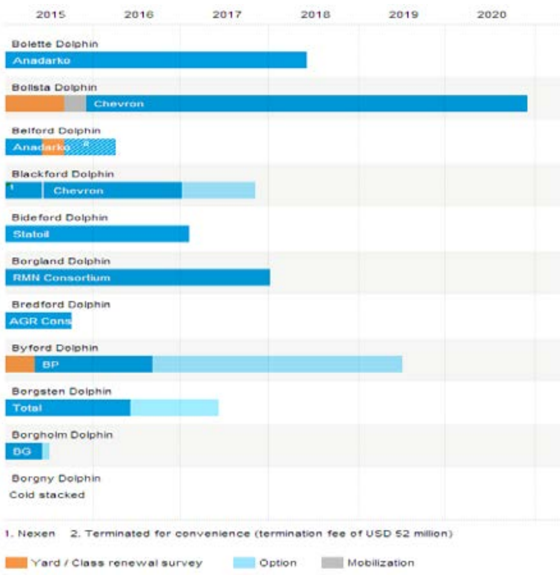


Figure 2-1: Current fleet contract status. FOE (2015)

2.2 Bolette Dolphin

To be able to use as reliable data as possible, data used in the thesis is found in SAP, connected to Bolette Dolphin. This is the newest drillship and have been in operation for approximately 1 year. In addition this is the only MODU so far that uses SAP as its CMMS. Four of Dolphin Drilling's MODUs are in the process of implementing SAP so far. In the future, the rest of the fleet will maybe implement SAP. It is therefore important that the basis of the spare part framework builds on data available in SAP or available from other CMMSs.

2.3 SAP

SAP is the maintenance and material management system DD has implemented for Bolette Dolphin. In SAP all maintenance orders, both corrective and preventive, are planned. Preventive maintenance orders are generated automatically for all functional locations with a generic maintenance concept. Corrective maintenance orders are created after a notification (failure report) is raised, reviewed and approved. Then a corrective maintenance order will be created and prioritized based on several factors, including consequence classification and failure type, whether or not it is an SCE, material availability, etc.

As a material management system SAP is used for purchasing materials, stock control, shipping information. When all materials are in SAP it is easy for the offshore crew to see where it is stored, if the material is in transit and when it is delivered, etc. There are several advantages of using SAP for both material and maintenance management:

- Linking work orders with materials
- More efficient planning of maintenance
- Trending failures, leading to the possibility of using the MODUs failure rates when stocking spare parts
    - Continuously improving maintenance and spare part management by trending usage of spare parts for preventive and corrective maintenance
- Resource planning, both of crew and materials needed for operation and maintenance
- Tracing costs, as both materials and work hours are logged and linked to the work orders

In the two next sections the technical hierarchy of SAP and consequence classification will be explained.

2.3.1 Technical hierarchy

The technical hierarchy is the foundation of maintenance management. It describes the technical structure of the MODU by uniquely identifying functional locations, often referred to as tag numbers. It shows how main equipment are connected technically and shows the physical relationship between main equipment, and underlying equipment, spare parts, as well as other equipment. According to NORSOK Z-008 (2011), the purpose of the technical hierarchy is:

- Showing technical interdependencies of the installation
- Retrieval of tags, equipment and spare parts
- Retrieval of documents and drawings
- Retrieval of historical maintenance data from CMMS
- Planning of operations
- Cost allocation and retrieval
- Planning and organization of the maintenance program
- Planning of corrective work

Functional locations is the identification of where equipment is located on the rig. DD use the SFI coding standard for identification of functional locations. SFI coding is an acknowledged system for creating a technical hierarchy of MODUs and vessels. The SFI standard is used for building the system in a logical manner in the CMMS. This way all functional locations are identified similarly, which makes it clearly what functions the functional locations provide. Figure 2-2 shows the general structure of identifying a functional location, with a few exceptions, used for technical hierarchy in DD:

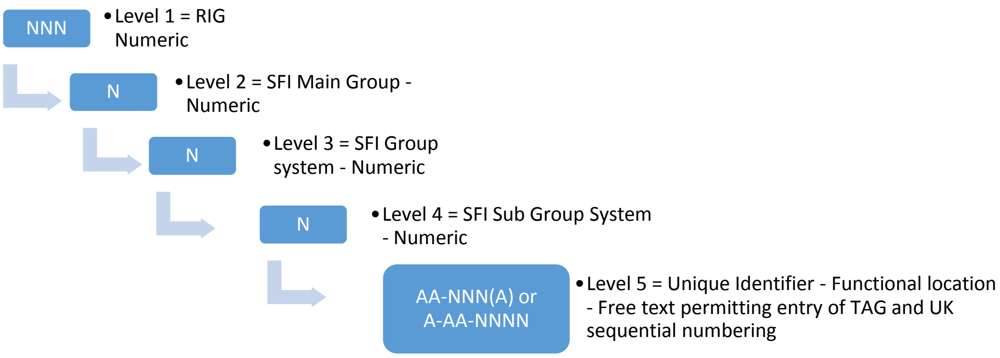
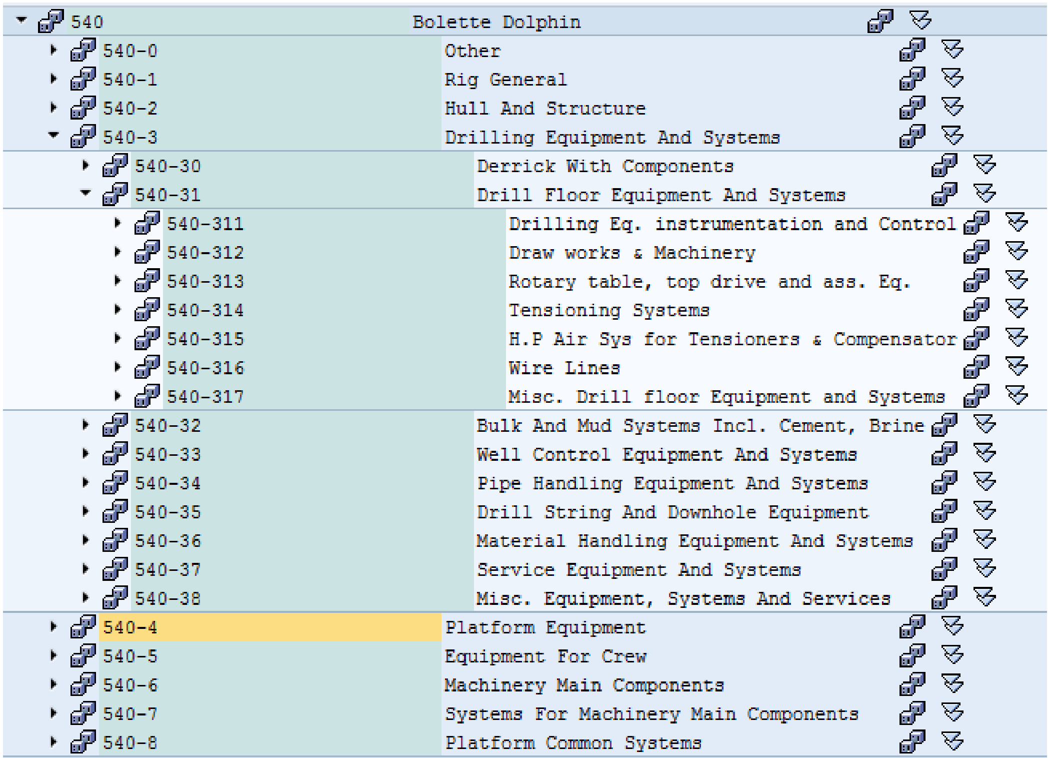


Figure 2-2 SFI coding system. N=Numeric, A=Alphanumeric.

The SFI coding can be illustrated with an example, functional location Drawwork, Ahd 1250 Main (540-312-BG-0001A). 540 is the rig Bolette Dolphin and is not included in the SFI structure. The first digit, 3, represents the main group, “Drilling Equipment and Systems”. “The second digit, 1, represents the group, “Drill Floor Equipment and Systems”. The third digit in the SFI code represents the sub group, in this case “Draw works & machinery”. Underneath this sub group functional locations connected to draw works & machinery are found.



540	Bolette Dolphin
540-0	Other
540-1	Rig General
540-2	Hull And Structure
540-3	Drilling Equipment And Systems
540-30	Derrick With Components
540-31	Drill Floor Equipment And Systems
540-311	Drilling Eq. instrumentation and Control
540-312	Draw works & Machinery
540-313	Rotary table, top drive and ass. Eq.
540-314	Tensioning Systems
540-315	H.P Air Sys for Tensioners & Compensator
540-316	Wire Lines
540-317	Misc. Drill floor Equipment and Systems
540-32	Bulk And Mud Systems Incl. Cement, Brine
540-33	Well Control Equipment And Systems
540-34	Pipe Handling Equipment And Systems
540-35	Drill String And Downhole Equipment
540-36	Material Handling Equipment And Systems
540-37	Service Equipment And Systems
540-38	Misc. Equipment, Systems And Services
540-4	Platform Equipment
540-5	Equipment For Crew
540-6	Machinery Main Components
540-7	Systems For Machinery Main Components
540-8	Platform Common Systems

Figure 2-3: Technical hierarchy of Bolette Dolphin . Screenshot from SAP

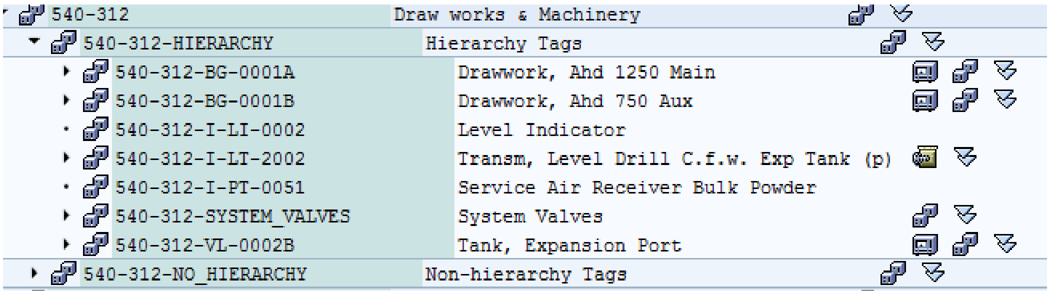


Figure 2-4: Draw works & machinery hierarchy

The functional location for the main draw work is 540-312-BG-001A. Underneath the functional location is the equipment number and underneath the equipment the material number. The figure below how the structure is built from main group down to the material.

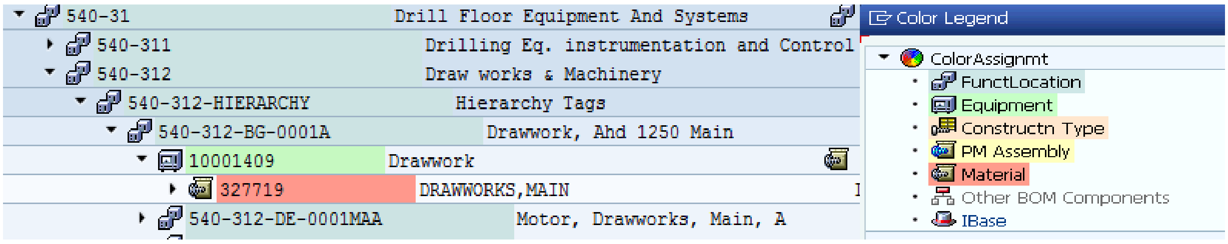


Figure 2-5: Hierarchy down to material and description.

A material number is given to each unique item in the system. Connected to main materials, referred to as BOM header materials, such as 327719 “drawworks, main” is the bill of materials (BOM). From the structure it can be seen that it has underlying materials shown by an arrow to the left of the material number. The BOM is a list of all spare parts of the BOM header material.

2.3.2 Consequence classification

The consequence classification for the technical hierarchy is done on a function level. Meaning that the function each equipment provides, is consequence classified. All functional locations in the technical hierarchy has been evaluated by DD. The consequence classification has to be done accordingly to NORSOK Z-008 which describes requirements to consequence classification and maintenance processes for offshore activities, it is a requirement for all offshore installations to have a consequence classification for functional locations. An example of a consequence classification is shown in figure 2-6.

“The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. Furthermore, NORSOK standards are as far as possible intended to replace oil company specifications and serve as references in the authorities regulations" (Standard.no, 2015).

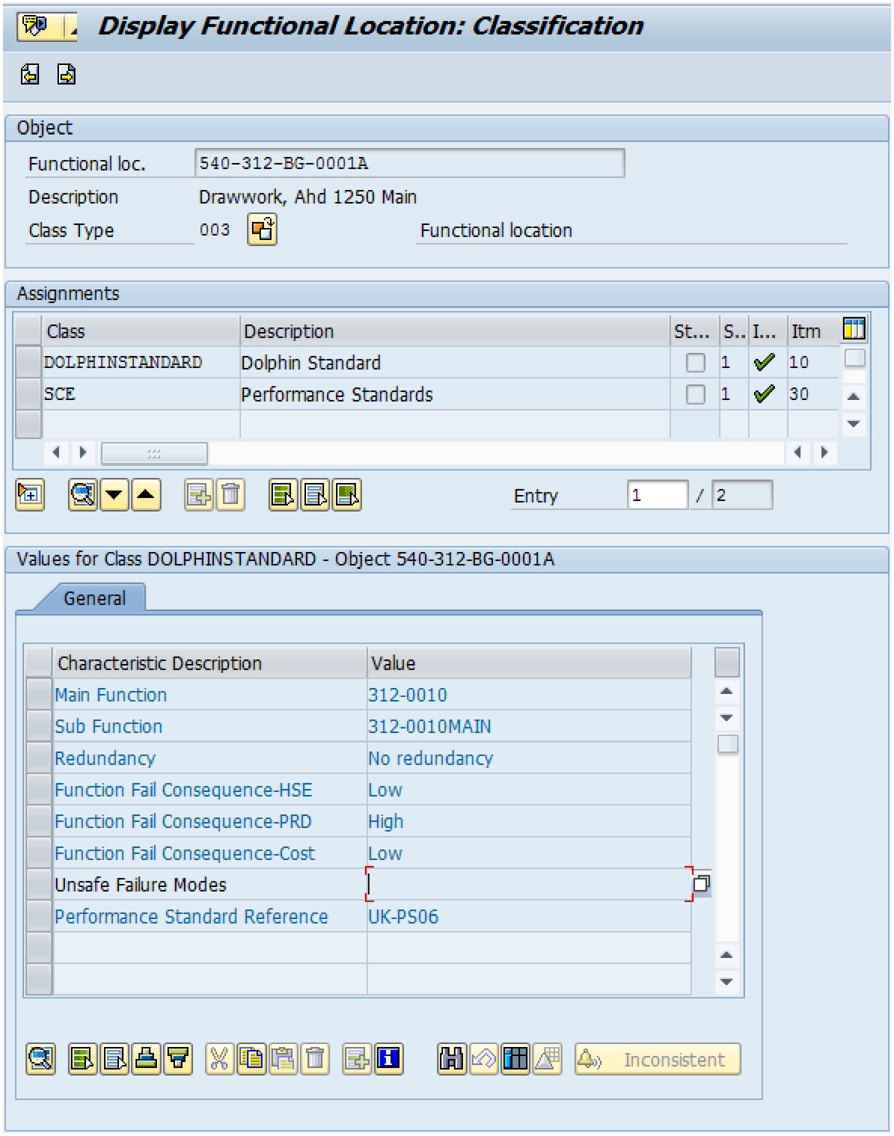


Figure 2-6 Consequence classification as shown in SAP

The consequence classification is done in DCT, which is the Dolphin Classification Tool. When performing the consequence classification the risk matrix shown in figure 2-7 is used. The consequence categories are HSE, Production and Cost. HSE is divided into injury and emission to environment to cover all equipment types.

	Consequence category								
	Injury	Emission to environment							
Conseq. class		Oil	Chem Grp 1	Chem Grp 2	Chem Grp 3	Cost Loss	Prod Loss	Modified By	Modified At
	Health, security and environment (HSE)								
	S	O	G1	G2	G3	C	P		
H	Death or disabled	> 500 m3	> 1 m3	> 10 m3	> 100 m3	> 3 mill	> 12 Hours	system	21.12.2012 09:17:55
M	Severe	> 100 m3	> 200 liter	> 1 m3	> 10 m3	> 1.5 mill	> 2 Hours	system	21.12.2012 09:17:55
L	Treatment or first aid	< 100 m3	< 200 liter	< 1 m3	< 10 m3	< 1.5 mill	< 2 Hours	system	21.12.2012 09:17:55
The highest value of these 3 columns indicates the classification value of the whole function as shown below.									
	Health, safety and environment (HSE)					C	P		
	The highest value is placed in one of the five columns in the above table. The highest value of these indicates the classification value related to HSE.								

Figure 2-7: Consequence classification matrix from DCT

The results of the consequence classification is transferred into SAP, which makes the results available for everyone with a user in SAP. In DCT comments to the classification can be made, these comments are visible when opening the functional location in DCT at a later point. With large functional locations, the consequence classification is discussed in meetings with offshore and onshore personnel to be able to make the best judgment. There are no formal minutes of meeting, but the arguments can be seen in the field for comments in DCT. The consequence classification is important, because decisions such as maintenance plans and spare part stocking uses the classification as a basis for how much effort and money are put into maintaining the function. The consequence classification is used for deciding criticality of functional locations, but it is not enough for determining spare part stock levels. To fully determine the need for spare parts, also other parameters must be evaluated (These are further discussed in section 5.3).

It is a field for performance standard in the consequence classification picture in SAP. This shows which UK performance standard that is relevant for the specific tag, and within the performance standard safety critical elements are described.

The functions degree of redundancy is determined in the consequence classification of functional locations. Redundancy is given values A, B, or C, which respectively means "No redundancy", "One parallel unit" and "Two or more parallel units". The ABC indicator is a combination of the highest failure consequence (high, medium, low) and redundancy expressed by a value as shown in figure 2-8.

A	ABC indicator text
1	Consequence L, Red A
2	Consequence M, Red A
3	Consequence H, Red A
4	Consequence L, Red B
5	Consequence M, Red B
6	Consequence H, Red B
7	Consequence L, Red C
8	Consequence M, Red C
9	Consequence H, Red C
A	Administrative FL
N	Criticality N/A
Y	Crit. to be decided
Z	Crit. not defined

Figure 2-8: ABC indicator, as used in SAP.

3 Maintenance and spare parts theory

In the oil and gas industry different maintenance strategies are applied. In this chapter maintenance is presented from a historical viewpoint, and main features of RCM is described. DD has based their maintenance strategy on RCM and equipment manufacturers' recommendations.

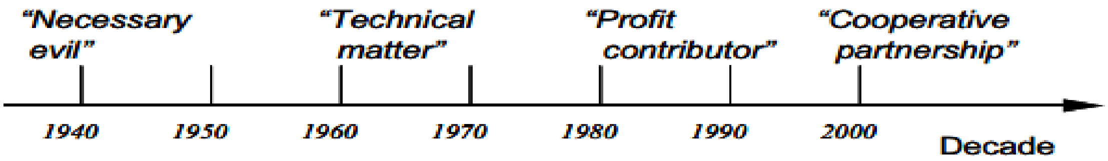


Figure 3-1 Maintenance in a time perspective (Pintelon, Parodi-Herz, 2008:p26)

From the 1940s and earlier, the maintenance function has evolved from a "necessary evil" to an important function of operating facilities. The phrasing "necessary evil" means that repairs and replacements were done only at failure or otherwise necessary. There were no concerns regarding optimization of maintenance. When maintenance were later seen as a technical matter, optimizing technical maintenance solutions began, the maintenance organization also began to receive attention. After the 1970-1980s the profit of maintaining machines began to be acknowledged. By using resources to maintain equipment, the availability improved, thus further increased revenues of organizations.

> *"Now maintenance management has become a complex function, encompassing technical and management skills, while still requiring flexibility to cope with the dynamic business environment. Top management recognizes that having a well thought out maintenance strategy together with a careful implementation of that strategy could actually have a significant financial impact. Nowadays, this has led to treating maintenance as a mature partner in business strategy development and possibly at the same level as production. In turn, these strategies formally consider establishing external partnerships and outsourcing of the maintenance function."* (Pintelon, Parodi-Herz, 2008:p26)

Spare parts is an important part of maintenance, if the necessary spare parts are not available, replacing defect parts of machines are not possible. This makes it important thoroughly evaluate which spare parts to keep available, and which spare parts to purchase when required based on the consequences of equipment failure.

3.1 Reliability centered maintenance

According to the Electric Power Research Institute (EPRI, 1991) RCM is a systematic consideration of system functions, the way functions can fail, and a priority-based consideration of safety and economics that identifies applicable and effective PM tasks. “The main objective of RMC is to reduce the maintenance cost, by focusing on the most important functions of the system, and avoiding or removing maintenance actions that are not strictly necessary” (Rausand, 1998). All maintenance tasks considered in RCM are related to failures and functional degradation, and ensures the designed reliability of the equipment is realized.

The only way of improving a systems reliability is in the design phase, therefore it follows that RCM does not improve the systems reliability, but it designed to ensure that the systems reliability is maintained throughout its expected lifetime. It is also designed to balance costs and benefits to obtain a cost efficient maintenance strategy. A common mistake is to believe that a machines performance and reliability increases with amount of maintenance. This is a mistake because often maintenance-induced failures occur, for instance oil contamination. Each maintenance task in an RCM strategy address a failure mechanism and provide a reduced expected loss related to function failure, personnel injuries, environmental damage, production loss and material damage.

There are a variety of different ways to perform an RCM analysis, but the essence of the analysis is always the same. Vatn (1996) has proposed a series of 12 steps to perform the analysis.

1. Study preparation
2. System selection and definition
3. Functional failure analysis (FFA)
4. Critical item selection
5. Data collection and analysis
6. FMECA
7. Selection of maintenance actions
8. Determination of maintenance intervals
9. Preventive maintenance comparison analysis
10. Treatment of non-critical items
11. Implementation
12. In-Service data collection and updating

Step 1 and 2. Study preparation consists of establishing a project group and clarifying the objectives and scope of the analysis. Documentation of the system chosen to analyze should be made available. This include drawings, operation and maintenance manuals, piping and instrumentation drawings, etc. System selection should be based on which systems that will benefit of an analysis, and should be conducted on the highest practical level. In DD case this is at sub-group or functional location level. The analysis is performed for all sub-groups of the plant Bolette Dolphin, the sub-group or functional location will further be referred to as systems. The reason for the highest possible level is that it makes the function definition easier and more covering.

Step 3. Functional failure analysis has three objectives;

i. Identifying and describing the systems required functions and performance criteria
ii. Describing input interfaces required for the system to operate
iii. Identifying the ways in which the system might fail to function

Functions can be sorted in groups, either online- or offline functions, or essential-, auxiliary-, protective-, information, and interface functions. The reason for sorting all functions under these groups is to be sure that all functions of a system is taken into account and functional failures are considered in the analysis. The third objective of the FFA is to list all failures modes of the system, to do this a FFA sheet may be used. Similarly to consequence classification of the functional location criticality is decided on a plant level. The reason for including criticality here is that low criticality levels of functional failures can be disregarded in further analysis, this limits wasting money on unnecessary failure modes. The four consequence classes are safety of personnel (S), environmental impact (E), production availability (A), costs/material loss (C). DD has combined safety and environmental impact to an HSE class. The criticality classes may be ranked as high, medium, low, and negligible, and if one or more classes are ranked as high or medium the functional failure should be subject to further analysis.

Operational mode	System function	Function requirements	Functional failure	Criticality				Frequency
				S	E	A	C	

Table 3-1 Rausands (1996) proposed FFA sheet

Step 4 is to identify the analysis items that are potentially critical with respect to the functional failures identified in step three. In some systems these functional failures may be easy to identify, but for more complex systems these items demand more effort to find. They can either be found by discussion or analyzing programs. These critical items are referred to as functional significant items, or FSIs. It is also recommended to identify items with high failure rate, high repair cost, low maintainability, long lead time for spare parts, or items requiring external maintenance personnel, these items are referred to as maintenance significant items (MSI). MSIs are analyzed to identify potential failure modes and effects in the FMECA in step 6.

Step 5. Data collection and analysis is an important step, but often it is difficult to get reliable data. Typical data needed to perform an FMECA is design data (capacity, equipment type), operational and failure data (operating hours, failure times), and reliability data (MTTF, aging). These data are either collected from operating experience, or data handbooks such as OREDA. Although much external data are available it is important to be critical to such data due to the course level and uncertainty associated with this data.

Step 6. Failure modes, effects and criticality analysis (FMECA) is performed to identify dominant failure modes of the MSIs. There are different types of work sheets that are used for this practice, an example is Table 3-2.

<table>
<tr><td colspan="15">System:
Ref drawing no</td><td colspan="5">Performed by:
Date:</td><td>Page:
Of:</td></tr>
<tr><td colspan="3" rowspan="2">Description of unit</td><td rowspan="3">Failure mode</td><td colspan="8">Effect of failure</td><td rowspan="3">MTTF</td><td rowspan="3">Criticality</td><td rowspan="3">Failure cause</td><td rowspan="3">Failure mechanism</td><td rowspan="3">% MTTF</td><td rowspan="3">Failure characteristic</td><td rowspan="3">Maintenance action</td><td rowspan="3">Failure characteristic measure</td><td rowspan="3">Recommended interval</td></tr>
<tr><td colspan="4">Consequence class</td><td colspan="4">“Worst case” probability</td></tr>
<tr><td>M SI</td><td>Operati onal mode</td><td>Funct ion</td><td>S</td><td>E</td><td>A</td><td>C</td><td>S</td><td>E</td><td>A</td><td>C</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 3-2 FMECA worksheet proposed by Rausand (1996)

This worksheet is quite detailed, and there are some worksheets that are less detailed but follow the same principle. In this work sheet the fields to the right of “Criticality” should only be used if criticality is ticked off with “yes” These columns are as explained by Rausand (1996):

MSI: The analysis item, in this case the functional location, tag number.

Operational mode: Depending on the MSI, equipment may have various operational modes, for example running and standby

Function: Depending on the operational mode the equipment may have multiple functions, such as close on demand for a valve.

Failure mode: The failure mode is the way a failure is observed, and defined as non-fulfillment of a function.

Effect of failure: The effect of a failure is described in terms of the worst possible outcome for S, E, A, C categories explained in step 3.

Worst case probability: The probability of an equipment failure giving the worst case outcome. At this stage of the analysis, a descriptive measure of the probability may be used.

MTTF: Mean time to failure for each failure mode. The measure of MTTF may vary from equipment to equipment depending on what is appropriate for the equipment in question. An example may be hours of operation.

Criticality: This field is a yes/no field, and is determined by taking probability, MTTF and failure effect into account. If they are ticked off as critical, the failure mode is dominant and will be taken through the next steps.

Failure cause: There may be several failure causes for each failure mode. This is typically component failures, or supporting equipment failure.

Failure mechanism: Examples of failure mechanisms are fatigue, wear, and corrosion.

% MTTF: A percentage of MTTF for each failure mechanism. This will only be an approximation due to the interdependence of various failure mechanisms.

Failure characteristic: How the failure propagates. This can be divided in three classes. The propagation may be measured by indicators (condition monitoring), as seen in gradual failures. Age-dependent failures, typically seen when there is a predictable wear out limit. Or complete randomness, referred to as sudden failures. The failure cannot be predicted by indicators or age.

Maintenance action: For each failure mechanism there is an appropriate maintenance action, this is found in step 7.

Failure characteristic measure: For gradual failures condition monitoring indicators may be listed. Aging failures may be described by an aging parameter.

Recommended maintenance interval: The interval between consecutive maintenance tasks. This length is determined in step 8.

Step 7. Selection of maintenance actions is where all dominant failure modes are analyzed to find effective PM tasks, the ones marked with yes in the criticality column. It will be determined if there are applicable and effective PM tasks, or if it is more economical to let the item run to failure and carry out corrective maintenance. In general there are three reasons for performing preventive maintenance; prevent failures, detect the propagation of failures, or discovering hidden failures. Five different types of maintenance tasks are considered, with different criteria to be applicable:

1. Scheduled on-condition task
2. Scheduled overhaul
3. Scheduled replacement
4. Scheduled function test and first line maintenance
5. Run to failure

Scheduled on condition tasks is tasks to determine the condition of an item, for example by condition monitoring such as vibration measurements. This is only applicable if it is possible; to detect reduced failure resistance for failure modes, to define a potential failure condition that can be detected by an explicit task. And if there is a reasonable consistent age interval between the detection of reduced failure resistance and time of failure.

Scheduled overhaul of equipment is performed before a specified age limit. This is seen frequently in the offshore industry by requirements in the NORSOK standards for different equipment, for example 5 year recertification of BOPs. This is applicable if there is an identifiable age where there is a rapid increase in failure rate, a large proportion of the units must survive to that age, and it is possible to restore the original failure resistance by repair.

Scheduled replacement of an item or parts of an item before a specified age limit is applicable if the item is subject to a critical failure. Test data show that failures are not expected until a specified age. The item is subject to failures causing major economic consequences. There is an identifiable increase in the failure rate at a certain age. A large proportion of units must survive to that age.

Scheduled function test and or first line maintenance such visual checks is scheduled condition assessment tasks or inspections to identify failures. These kinds of tasks are applicable if the item is subject to failures that is not evident under normal operation and no other types of tasks is applicable and effective.

Run to failure will only be an option when no other tasks is possible or economically favorable compared to failure consequences. Typically when the functional location failure consequence is low. For example for small equipment which has low cost, are easy to replace, and/or have redundancy.

These tasks and criteria are only meant as guidelines, and will not cover all situations. Sometimes combinations of maintenance tasks are more suitable than only one type of task. It must also be emphasized that preventive maintenance does not prevent all failures. Many may be prevented or found before they have consequences, this is why maintenance is important, but there will always be circumstances leading to failure beyond what is expected. This may be a result of design error, misuse of the equipment or equipment standing still for a period. When the maintenance tasks are decided it should be an easier exercise to choose what spare parts that will frequently be needed. This can be seen from the functional failures and failure modes identified by the FFA and FMECA, and one can compare these lists with the recommended spare part lists provided by the equipment manufacturer.

Step 8. Most of the PM tasks are done at a regular basis. That means that the interval for the PM tasks must be set, which is step 8 in Vatns (1996) 12 step process. Deciding the PM interval is a difficult task, and has to be based on knowledge about the failure rate function, consequences and cost of failure that the PM task is designed to prevent, as well as balancing the interval with the cost of performing the PM task. Because the knowledge of failure rate functions are often inaccessible, general guidelines regarding maintenance intervals from the original equipment manufacturer is used as a starting point. After a while this interval is evaluated, and the frequency is adjusted up or down. This is also how DD has established their PM task intervals.

Step 9 is a preventive maintenance comparison analysis. There are two criteria for choosing maintenance tasks in RCM analysis, and both need to be met. The two criteria is applicability and cost effectiveness. A PM task is applicable if it can eliminate or reduce the probability of a failure, or it can reduce the impact of a failure. The cost effectiveness criteria is met if the maintenance task cost less than not performing the task. Or that the task is cheaper than the failure the task is to prevent. Costs of PM tasks include both indirect and direct costs. Examples of costs are:

- Costs related to maintenance induced failures
- Use and cost of physical resources, eg. spare parts
- Production unavailability during maintenance
- The risk that maintenance personnel are exposed to during PM tasks

Examples of failure costs are:

- Production unavailability (downtime)
- Emergency repair costs

Step 10. Treatment of non-MSIs. For non-MSIs a brief cost evaluation of the established may be performed, and if it is found insignificant it is reasonable to continue this program. If not it should be reduced for example by introducing longer intervals between PM tasks.

Step 11. Implementation. After the RCM analysis is finished and PM tasks and intervals are decided, it is important to have dedicated personnel to implement the PM tasks in the CMMS, in DD' case SAP. This personnel should also train the performing maintenance personnel on how the PM program is shown in the CMMS so it will be easy for the maintenance personnel to find out which tasks they shall perform when.

Step 12. In-service data collection and updating. A major advantage with the RCM analysis is that the basis of PM tasks are systematically analyzed and documented. It is therefore easy to update the experience and information decisions are made from, this is an advantage because the experience and information about failure rates before the analysis is often scarce. When updating the information after failures, it may become evident that PM tasks should be done differently or more frequent and thus the PM program will become better with years.

Spare parts are not the main focus of RCM analysis, but in the analysis and especially in the FMECA step potential failures becomes clear. Based on that step it becomes evident which spare parts that may be useful to have on site, or stocked onshore at a main warehouse. When classifying failures as critical, one may also see a clearer picture of which spares that are absolutely necessary to have in case of failure and full stop of the equipment. Some failures cause downtime, in those cases it is important to have the necessary spare parts available, or at least in the main warehouse.

3.2 Spare parts

There are four main categories of spare parts, capital/insurance spare parts, operational spare parts, consumables, and obsolete spare parts. Capital spares are only stocked in the cases when failure of an equipment will cause long operational down time due to long repair times and long lead times. An example is keeping an extra BOP in case of failure. If the subsea BOP fails, it will typically take two days to raise the BOP from the seafloor then x hours to repair it and then two days to put it back on the seafloor in addition to the time needed to provide spare parts, or a complete BOP. If there is a major failure which takes long to repair, lost income due to down time quickly is saved by having a backup BOP. Operational spares are spare parts used for maintenance activities and forecasted breakdowns/failures, these spares may be repairable. Consumables are spares that are used once and scrapped at failure. Obsolete parts can be seen as dead inventory, or parts that belong to equipment that is removed, and has been left in the inventory and induce an extra cost.

Recent maintenance research classifies spare parts differently, using different measures of criticality and parameters. To further complicate spare part classification, different researchers rely on different factors in order to classify types of spare parts as well as different classes to put spare parts in. Important factors for spare part classification are; criticality classification of the functional location, consequence of non-availability of part, lead-time, and cost. This list is not exhaustive, as other factors may influence spare parts depending on the facility, and organization/company preferences.

NORSOK Z-008 (2011) gives an example of classification of spare parts. This is as follows.

- *Capital Spare Part*
  - *Vital to the function of the plant, but unlikely to suffer a fault during the lifetime of the equipment;*
  - *Delivered with unacceptably long lead time from the supplier and usually very expensive;*
  - *Often these spare parts are characterised by a substantially lower cost if they are included with the initial order of the system package;*

- *Operational Spare Parts*
  - *Spare parts required to maintain the operational and safety capabilities of the equipment during its normal operational lifetime;*
- *Consumables;*
  - *Item or material that is not item specific and intended for use only once (non-repairable).*

SAP refers to each unique item as a material and each material has its unique material number. Three material classes are used, ZCPX, ZSPR, ZCON: Assets are grouped as ZCPX. These items are installed on the rig and have a planned maintenance program. Equipment that have a lifetime longer than 3 years, value of more than $25 000, and are repairable (maintainable), ZCPX are typically complete machines such as BOPs, drawworks, generators. ZSPR is spare parts used for maintenance and operational requirements of assets and equipment. Typical spare parts are BOP rams, valves, etc. ZCON is consumables, these items is not controlled/counted by the system. Typical consumable materials are tools, electrical consumables, oils and greases. Other than these classes, the criticality of spare parts is not further classified in SAP. In order to be able to achieve the objective of this thesis, the spare parts has to be classified in more detail, which is discussed in section 5.3

Type	**Value**	**Costing**	**Serialization**	**MRP-type**	**PM-BOM**
ZCPX	Owner's fixed asset	Depreciated by owner	Usually	PD	Usually not
ZSPR	Held on stock	At goods issue	Some times	VB or PD	Possible
ZCON	None	At Goods Receipt	Never	ND	Not possible

Table 3-3: Dolphin Drilling's categorization of materials. (Courtesy of DD)

MRP is an abbreviation for Material Requirements Planning. Materials are separated in three MRP-types; PD, VB, or ND. The reason for separating in different types, is that all materials does not require the same inventory control.

Materials with PD as MRP type are procured when needed, and replaced like for like. ND means no planning, when a material is under the MRP-type ND, the storekeeper offshore creates a material requisition when the stock begins to get short. Typical materials categorized as ND are consumables. These items are not counted often or connected with a PM task. It is not set a reorder point or a maximum stock level. It is only important that the items are available.

VB MRP-type is manual reorder point planning. All materials with MRP-type VB has a reorder point and maximum stock level in SAP. The reorder point and maximum stock level are set based on the needs flagged by different disciplines, and are in many cases too high. For VB items, the storekeeper create material requisitions based on counting lists and consumption. When the stock level is at or close to the reorder point he/she will create a purchase requisition for the material.

PM-BOM means that a bill of materials can be attached to the preventive maintenance task. When a purchase requisition has been made by the storekeeper offshore, saying “we need these materials”, this goes to the procurement department onshore which handles the purchase requisition further. The onshore purchaser finds the best suited vendor and makes sure DD gets the best price and delivery terms.

3.2.1 Criticality classification of spare parts

Materials has now been classified as capital spares, spare parts, and consumables. This does not say much about how important it is, or how many that should be stocked. To determine importance of each spare part, a more detailed classification must be done. There are many different methods of classifying spare parts, and analyses such as ABC and VED (Vital, Essential, Desirable) are commonly used for inventory control. Much of the research regarding spare part classification and optimization is directed towards production systems and supply chain management, and take advantage of predictable behavior when optimizing inventories.

ABC analysis classifies spare parts within classes A, B and C depending on value of the spare parts (Niebel, 1994, pp 112-113). Class A represents approximately 10-15% of the total items, but the monetary value is between 70-85% of the total inventory. Class B represents approximately 20-30% of the items, but approximately 25% of the total inventory value. Class C represents 60-70% of the items, but only approximately 10% of the inventory value. Class A require most inventory control. Class B require less control, and class C the least amount of inventory control. This is due to the large differences in inventory value of the different classes. The differences of value makes class A most profitable to reduce by improving spare part strategy.

VED analysis aims to classify spare parts according to their criticality for the facility. The degree of criticality of production is determined by stating a spare part is vital for the production process, essential for the production process, or desirable for the production process. For DDs case, this criticality can be based on the consequence classification of the functional location the spare part belongs to.

To solve the objective of this thesis, these classification methods are insufficient, as there are several other parameters that has to be taken into consideration for an organization operating MODUs. Gajpal et al. (1994) suggests using the analytical hierarchy process (AHP) for determining criticality of spare parts as vital, desirable and desirable. This process quantitatively determines a spare parts importance and in the end classifying it as vital, essential or desirable. In the thesis this process was used to weigh parameters of the functional location and material against each other, in order to find the most influential parameter (this process is explained in section 5.3). In the thesis this technique had to be used because some characteristics are more important than other when deciding stock levels of spare parts. In the thesis a separate spare part classification has been implemented, instead of classifying spare parts corresponding to the consequence classification of the functional location, as material attributes such as number installed and lead time are important when deciding stock levels.

3.2.2 Rules and regulations regarding spare parts

The Petroleum Safety Authority Norway (PSA) has in the activities regulations has defined a set of rules and regulations all actors has to follow, in order to be allowed to operate on the NCS. Among this set of regulations chapter IX covers maintenance activities. Section 46, classification states that:

> *Facilities' systems and equipment shall be classified as regards the health, safety and environment consequences of potential functional failures.*
> *For functional failures that can lead to serious consequences, the responsible party shall identify the various fault modes with associated failure causes and failure mechanisms, and predict the likelihood of failure for the individual fault mode.*
> *The classification shall be used as a basis in choosing maintenance activities and maintenance frequencies, in prioritising between different maintenance activities and in evaluating the need for spare parts. (PSA, 2015):*

This regulation is covered by the consequence classification and RCM analysis. As the framework incorporates the classification when deciding spare parts it is operating within the regulation of PSA. In addition to rules and regulations enforced by PSA, there are recommended practices from the American Petroleum Institute (API) which most drilling actors follow. Within the API standards they recommend minimum stock levels for different equipment, for example well barrier equipment such as the kill and choke manifold.

From API recommended practice 53 (1997) concerning blowout prevention equipment systems for drilling wells:

> *An adequate supply of spare parts is important for components subject to wear or damage or whose failure seriously reduces the effectiveness of the manifold. Standardization of components is recommended to minimize the inventory required. Although the inventory will vary from rig to rig, a generalized recommended minimum spare part list includes:*
>
> *a) One complete valve for each size installed.*
> *b) Two repair kits for each valve size utilized.*
> *c) Parts for manually adjustable chokes, such as flow tips, inserts, packing, gaskets, O-rings, disc assemblies, and wear sleeves … API, (1997, p19)*

The API recommended practices are updated from time to time and it is important to have the latest edition. As an example API recommended practice 53, was revised in 2012 and incorporated as a standard, not only recommended practice. As the framework is created in order to lower the spare part inventory, it is difficult to include all such recommended standards, and regulations, and it is encouraged that the user has knowledge concerning the use of such standards. Whenever a standard is applicable for spare part inventory of equipment, it is suggested to use that as a minimum requirement, and if the framework decides higher number of spare parts then the framework sshould be used.

4 Current Situation Analysis

Materials comprise spare parts (ZCPX and ZSPR), consumables (ZCON), tools and construction materials. Currently DD have coast bases in Tananger and Aberdeen for supplying the MODUs in the North Sea. On the coast bases DD have storage possibilities and a workshop. In addition to that materials are stored on MODUs. Control of spare parts and consumables is important to ensure that the necessary materials are available when needed, both for PM and CM. This involves optimization of spare parts based on demand, consequence of failure, repair time and cost, as well as linking spare parts to maintenance planning activities. In addition to this a consideration regarding stocking single components or pre-assembled units, as well as storage requirements of parts should be done. If storage requirements of spare parts are not considered, DD risks that spare parts become severely degraded and not discovering this before the spare part shall be used. Typical materials that degrade over time is gaskets, which require stable temperatures and low humidity. The focus is on stock levels in this thesis, assuming storage locations are sufficient, both in size and condition.

As explained capital spares valued as assets and are depreciated by a mother company, Dolphin Drilling PTE Ltd, in Singapore, during the lifetime of the rig. Because of this they do not have a value as a spare part in the spare part inventory. In this current situation analysis the value of capital spares is not considered, as they are not priced in SAP.

Today Bolette Dolphin have a spare part inventory valued at approximately $18 million USD. Some tables and charts present how the inventory is distributed. All data used in this thesis was exported from SAP 09.04.2015, at that point Bolette Dolphin had been in operation for approximately one year. First of all, the total value of spare parts is divided in actual stock, and material in transit, that is the material already ordered and on the way to the warehouse either offshore or at the main warehouse onshore.

	In Stock	**In Transit**	**Total**
Value ($)	16 930 383.38	1 201 476.60	18 131 859.98

Table 4-1: Value of inventory

The next chart shows the inventory value as a percentage over percentage of materials in the inventory. This chart includes all materials with a price higher than $0, in practice that means that all materials on stock with a price in SAP is included. In total that is 9089 materials, with a value of $18 178 759.40. The distribution follow Pareto's law. 15% of the materials account for 80% of the inventory value. This is due to the large differences in material prices, and it indicates that it is important to focus on expensive materials. The impact on total value of spare part inventory will be great if a framework manage to reduce the high priced items, without sacrificing operation downtime or HSE incidents. The impact on the total value of the inventory will not be seen from reducing the stock of gaskets that typically costs less than $20.

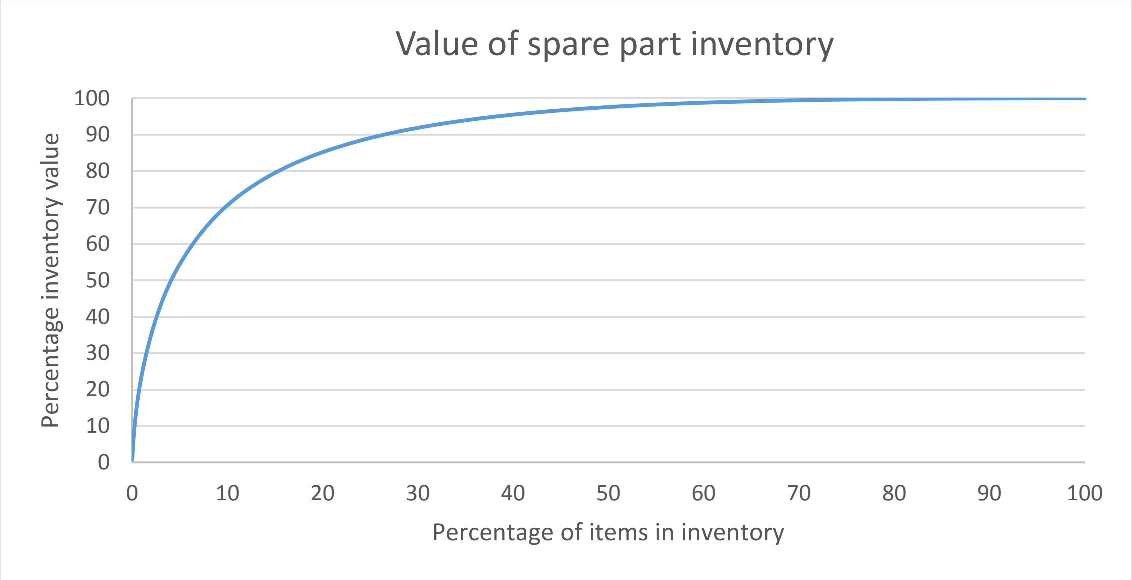


Figure 4-1: Value of spare part inventory in percent. The total inventory value follow Pareto's law, 15% of the materials comprise 80% of the value

4.1 Distribution of materials

DDs material management system consists of 25684 materials as shown in table 4-3. Furthermore the materials with a price in SAP is distributed according to table 4-2. Out of the 9798 spare parts with a price, 7525 has MRP type VB which means they have a reorder point and maximum stock level. All consumables has MRP type ND, and are planned lot for lot.

Material type	ND	PD	VB	Total
ZCON	2187			2187
ZSPR	6	2267	7525	9798
Total	2193	2267	7525	11985

Table 4-2: Distribution of materials with price>0.

Material type	ND	PD	VB	Total
ZCON	12968	2		12971
ZCPX	1	308		309
ZSPR	23	4423	7959	12405
Total	12992	4733	7959	25684

Table 4-3 All materials

4.2 Distribution of inventory value

In table 4-4 to table 4-6, some key numbers of the current inventory are displayed. The tables only include materials that are currently stocked. It can be seen that ZSPR materials with MRP type VB accounts for the largest part of the spare part inventory. That is spare parts with defined ROP and MSL. Consumables only account for 0.4% of the total inventory value. ZCPX are not priced in SAP, which is why they have a value of 0.

Spare part type

Material type	Total value
ZCON	73387.14
ZCPX	0
ZSPR	18105372.26
Total value	18178759.40

Table 4-4 Inventory value sorted by material types

All material classes

MRP type	Total value
ND	80565.52
PD	4505836.58
VB	13592357,30
Total value	18178759.40

Table 4-5 Inventory value sorted by MRP type

Only ZSPR parts

MRP type	Sum value
ND	7178.38
PD	4505836.58
VB	13592357.30
Total value	18105372.26

Table 4-6 ZSPR materials sorted by MRP type

Unfortunately not all spare parts are linked to functional location via BOMs, but out of 9089 4872 is linked against a functional location via BOMs. From figure 4-2 on the next page, 80% of the total value of these 4872 unique materials are distributed over 30% or 21 of 70 SFI groups. This gives reason to believe that the functional locations to the according SFI groups require most maintenance and replacement of parts in the present maintenance strategy. It is also an indicator that the most important equipment according to the consequence classifications are within these groups, and a large spare part inventory is a measure to lower the risk of downtime if equipment should fail, by having spare parts available.

The reason that BOM lists were used for the analysis is that the same BOM can be connected to many functional locations via the equipment number. When the query was run only sorting on SFI groups or functional locations, the results were misleading because the BOM is included in the result many times. As an example SFI group 651 – main diesel generator engines, one BOM is connected to 96 functional locations. From that result it looks like SFI group 651 has 13108 materials in BOM lists.

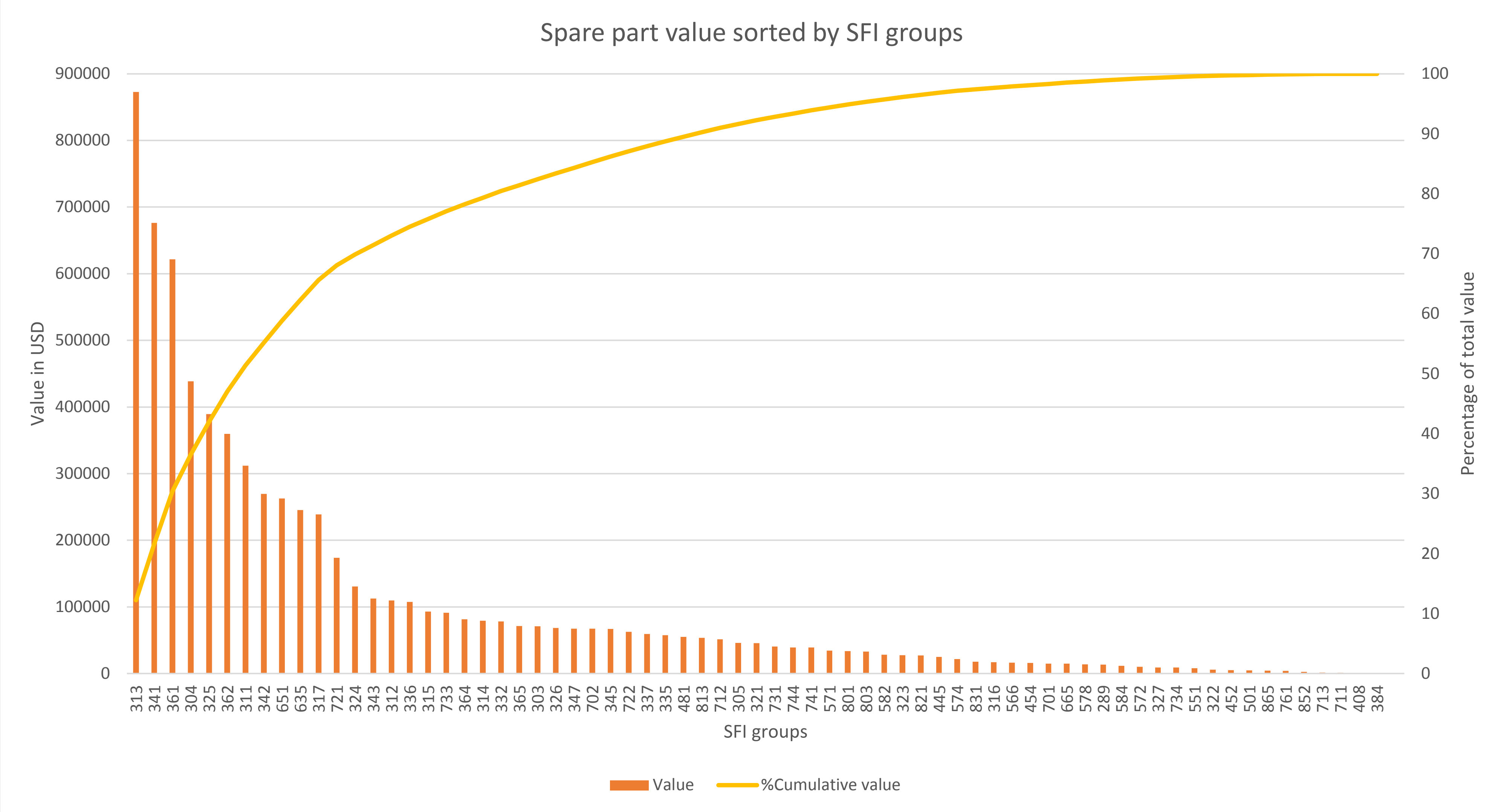


Figure 4-2 This figure shows the value of spare parts connected to each SFI .80% of the total value is allocated to 30% of the SFI. See Appendix A for all SFI group names.

The top 5 SFI groups are:

1. 313 – Rotary table, top drive and ass. equipment ($ 872 555)
   - Comprises 48 functional locations
2. 341 – Derrick mount vertical pipe handling systems ($ 676 095)
   - Comprises 157 functional locations
3. 361 – Deck cranes ($ 621 701)
   - Comprises 294 functional locations
4. 304 – Drill string heave compensator ($ 438 729)
   - Comprises 79 functional locations
5. 325 – Mud supply ($ 389 483)
   - Comprises 250 functional locations

The top 20 SFI groups accounts for approximately 80% of the spare part inventory. The top 5 groups account for close to 50% of the value.

The top 8 groups are associated with drilling equipment and systems, which is the main function of the MODU. It is therefore not unreasonable that they account for a major part of the spare part inventory. SFI groups 651 and 635 are respectively main diesel generator engines and thrusters, with respectively 966 and 271 functional locations. These two groups are very important as they provide electricity, and propulsion and positioning system.

There are large differences in spare part inventory value associated with the different SFI groups, as well as large differences in the number of associated functional locations. Some of the reason for the major differences in spare part inventory value is that for the SFI groups 651 and 635, many of the functional locations are similar. For example there are 96 functional locations for camshafts connected to SFI group 651. All these functional location share spare parts. As for the SFI groups connected to drilling equipment and systems, the functional locations are to a higher degree equipment specific, meaning they cannot share spare parts as much as SFI group 651.

4.3 Overstocking

Overstocked materials are the materials with higher on stock level than maximum stock levels. As a part of the current situation analysis, overstocked materials were found. To find overstock materials, the Access database, with form "frm_Overstock" was used (section 5.7.3.4). This form can only be run for materials with MRP type VB, because only VB materials has a defined ROP and maximum stock level. Table 4-5 shows that VB materials account for $13.6 million of the $18.1 million inventory. So the result of the overstock run, gives an indication of the overstocking tendency. The result showed that 926 materials is overstocked.

MaterialNum	MaterialDescription	MaximumStockLevel	MaterialPrice	OnStock	Overstock	OverstockValue
252558	KIT,SEAL,BONNET,15 1/2 MPL	4	6587	13	9	59283
312221	KIT,SEAL,BONNET	4	6652	12	8	53216
306677	MODULE,DISCHARGE,DNV	1	50070	2	1	50070
300235	PAD,SLIDE	2	2875	16	14	40250
305060	PUMP,DIAPHRAGM,FLANGED,3"	2	13371	5	3	40113

Figure 4-3 Example of overstocked materials from Microsoft access database

Figure 4-3 displays some of the overstocked materials. It displays the material number, description, maximum stock level, on stock, material price, how much overstocked the material is, and the value of overstocked items. The total value of overstocked materials is today $1.17 million. That means DD can make large savings just by following the current MRP settings.

4.4 Duplicate materials

A duplicate run on manufacturer part numbers in Excel revealed that 582 manufacturer's part numbers are used for two or more materials. Further materials could have been checked for duplicates based on material description, this further showed many duplicate materials. Based on these findings, it is apparent that DD should not create a new material number before a thorough search for the correct material has been done in SAP.

5 Development of spare part optimization methodology

5.1 Framework introduction

The purpose of holding spares is to facilitate timely repair and mitigate the consequences of a failure. When developing a framework for deciding spare part stock levels it is important to use enough data to make the results reliable, with the purpose of spare parts in focus. This is especially important if the consequences of not having spare parts available leads to production stop. The objective is to find the optimal balance between inventory cost and downtime cost which gives the lowest total cost, as seen in figure 5-1.

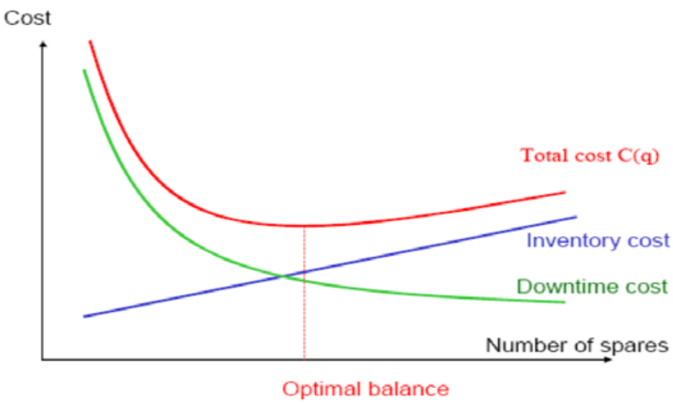


Figure 5-1 Balance between inventory cost and total cost. (Kumar, 2000)

In the framework developed in this thesis failure rates have been found in OREDA. As data from OREDA is collected from many different installations it is important that the users are aware of the uncertainties attached to failure rates they provide. Based on failure rates and historical data it is straightforward to calculate expected future consumption. In addition to expected consumption, consequence classification of the functional location, and availability of spare parts should be considered.

During the work with the thesis a database was built in Microsoft Access, containing relevant data from SAP. In the database relationships corresponding to the technical hierarchy for Bolette Dolphin were set up in order to have the most realistic starting point.

The framework for deciding spare part stock levels are created as forms in the database. These forms show all relevant data about materials and functional locations when using the framework to determine spare part stock levels. The optimization of stock levels is divided in two; deciding whether or not to stock a spare part, and to find the optimal stock level. A major advantage of using the framework is that DD gets a framework for spare part management which easily can be implemented across the organization and used to justify the spare part inventory. The three main functions of the framework are;

- Deciding if a spare part should be stocked or stocked when required
- Recommending a stock level for spare parts
- Showing overstock materials, in order to increase focus on high stock levels.

5.2 First decision: Stock or stock at failure

When managing the spare part inventory, two questions needs to be answered: “Do we need to stock this item?” If yes, then the following question is: “How many do we need to stock?”

Many considerations have to be made when deciding whether to stock spare parts or not. The OEM has their recommendations, the operational importance of the equipment, the availability of parts in the market, operational personnel’s opinions, as well as the company’s financial strength. Because all these considerations are made continuously there are often no specific procedure to follow when deciding to stock spare parts or not. This thesis combines some of these considerations in order to create a framework that gives a clear and reproducible answer to the question about the necessity of the spare part.

During the work with the thesis a decision criteria for stocking materials or not was defined: If the costs of stocking the spare part is lower than the costs of stocking at failure, the spare part should be stocked. In addition the probability of failure should be considered. If the probability is high, the material should be stocked, as it probably is necessary after some time of operation. This judgement is the basis of the first decision criteria; to stock a material or buy it when required. The costs of stocking at failure is to a high degree related to operational downtime and potential chain reactions causing further damage to the equipment after the initial failure. Possible costs of not having certain materials at hand may be that repair or improvement work is delayed causing further damage to the equipment or structure that should have been repaired. Thus the scope of the repair becomes bigger than it would have been if it is done shortly after the failure/discovery. This in turn causes the costs of the repair to increase. This is referred to as probable costs of not having material available.

5.2.1 Costs of stocking at failure

- Downtime cost due to unavailability
- Failure of other equipment as a chain reaction – due to eg. more wear or higher stress
- Premium of urgent orders

Thus the cost stocking at failure causing downtime

$$C_{stock\ at\ failure} = Price + Probability(R_D * Leadtime + premium)$$

The cost stocking at failure not causing downtime

$$C_{stock\ at\ failure} = Price + Probability(R_D + premium)$$

Where:
R_D= day rate, or extra cost due to unavailable spare causing a delay in the repair.
Probability = Probability of failure
Lead time = Time until material is delivered on site
Premium = The extra cost of making an urgent order

There are some materials that will not lead to downtime if they are unavailable at failure, but may lead to large costs due to degradation of equipment or structure of the rig. An example of this is surface treatment of structure. If the structure is not surface treated properly when there are damages, rust, etc. the chances are that the costs of fixing structure are higher than making the small investment of fixing it at the first opportunity. Another example are anodes that prevent corrosion, if there are not replaced when they are worn out, the structure will start to corrode and after some time the costs of fixing the structure after major corrosion is much higher than replacing the anodes. Because there are many such examples, the increased cost is referred to as “probable cost of unavailable spare”. This cost is up to the users to decide and is based on their knowledge and experience. As this cost varies from instance to instance it has to be a manual input in the framework.

5.2.2 Costs of stocking to storage

- Holding costs (*hc*)
  - Storage costs
  - Tied capital cost
- Procurement costs (*pc*)
  - Material cost
  - Order cost
- Logistics costs (*lc*)
  - Onshore transportation
  - Offshore transportation

Total cost of stocking a material is:

$$C_{s,i} = hc + pc + lc$$

5.2.2.1 Holding costs

Holding costs are separated in storage and tied capital costs. Storage costs are calculated a percentage of the material price. In the framework three sizes with associated storage costs is defined, these are given in the list below with storage costs as a percentage of the material price in the parenthesis.

- Small, anything that goes in a small box and can be transported by helicopter (1%)
- Medium, anything that needs its own pallet, cannot be transported by helicopter (3%)
- Large, anything that needs its own container or basket (5%)

Tied capital costs are the alternative cost of spending money on spare parts. In the thesis it is assumed that the alternative cost is getting interest on the money, in some research this interest is defined as the company's required return on investment or the interest that banks offer. This cost is calculated as

$$TCC = Price * Interest * Lifetime\ of\ rig$$

The interest may vary from year to year, but in the thesis the interest assumed to be 5%, but the user can easily change the interest rate.

5.2.2.2 Procurement costs per purchase order

Procurement costs includes all costs of purchasing the material. In the thesis procurement costs can to be entered manually, but is set to $22 by default, this is due to changing conditions in the company. The cost of procurement involves all processes for purchasing materials. Including time to create purchase requisition and order, reviewing, authorizing, and approving purchase orders, etc. In this thesis the salary of a procurer (approx. $67000) has been used as basis, and divided that by the average number of purchase orders made yearly which is around 3000. That leads to a sum of approximately $22 per purchase order. For simplification purposes the sum is fixed regardless of number of items on the purchase order. The actual cost of procurement is hard to measure precisely, which is why it is a manual input. The procurement cost can easily be changed by editing the default value in the form “frm_DecisionAid”.

5.2.2.3 Logistics costs

There are costs associated with transporting materials onshore and offshore, this is based on the size of the material, and needs to be entered manually due to lacking information about size and weight in SAP. Logistics costs are based on the same sizes as holding costs. The logistics costs for the sizes are

- Small = 1%
- Medium = 2%
- Large = 5%

Now that all costs are explained and included in the framework the first decision can be made based on the cost picture. The first decision is made in the form “frm_DecisionAid”. When using the framework data is gathered in order to decide on one of the two alternatives; Stock, or stock at failure. If the cost of stocking is less than stocking at failure, the spare part should be stocked. For explanation of how the framework was developed, see section 5.7.

5.3 Second decision: Deciding quantity to stock

If the result of the first decision is to stock the material, then the second decision that has to be made is how many to stock. This decision can be made by using the form "frm_decidesparequantity" (section 5.7.3.2). How many spares of each material to keep in stock depends on a variety of parameters. The main parameters the stock level depend on is listed below.

- Functional location consequence classification
- Redundancy
- Number installed
- Lead time
- Expected consumption

5.3.1 Why are these parameters important?

The functional location failure consequence classification says something about the consequences of failure of the functional location. As mentioned the consequence classification is divided in three; production, HSE, and cost. With regards to the spare part stock, the framework only use production and HSE failure consequence classification. The cost of failure cannot be reduced by keeping extra spare parts, this is connected to the value of the equipment and spares. If the production or HSE consequence classification is high it means that consequences of failure are severe. Then it is important to have available spare parts if the equipment should break down. In some cases function failure of equipment with high production or HSE failure consequences results in operational downtime, which DD want to avoid. This is why these two parameters are included when deciding the stock level.

Some equipment are redundant, other are not. Redundancy influences the stock level to be higher if there are no redundancy, if there is redundancy the importance of available spare parts are reduced.

Some materials are unique on the rig, while other materials are installed many places. If a material is installed many places this increases the need for spare parts because the likelihood of failure increases, as seen from the equation Total MTTF = MTTF/number installed. It is also more economically understandable to have more spare parts to materials installed many places compared to unique materials, assuming all else equal.

Lead time of materials affect the necessity of large stock levels. If materials are standard parts and easy to get a hold of from multiple suppliers, the required spare part inventory is lower than if the part has to be custom ordered. A factor affecting lead time is rig position. As Dolphin operates floating drill rigs and ships they may be located at different locations from time to time. Delivery time of materials procured from Norwegian suppliers delivered to a rig on the Norwegian continental shelf is very different than materials shipped to a rig located outside of Brazil. It is a bad situation of the rig is on downtime and regular delivery time for the necessary materials are 150 days. If this situation is probable, the materials should be stocked so the situation is avoided.

Expected yearly consumption is calculated as 8760/Total MTTF. 8760 is the number of hours per year. This serves as a benchmark of how many spares that should be stocked yearly, and is theoretically calculated. As this industry has learned, the theory does not always match with reality. That is why this number cannot fully be trusted. The expected consumption is used as a basis, and will be lowered depending on the other parameters' score (the scoring system will be explained in section 5.3.2).

The size parameter could have been included to this consideration. As an example small materials are easier to transport quickly to the rig by helicopter than large assemblies. By including a size parameter stock levels could possibly have further been reduced, but as there are no data in SAP regarding sizes or weight of materials it was decided not to include it. By including it the framework would have one more manual input which makes the framework heavier to use. The size parameter is included size in the first decision because it influences the total costs, but from an inventory side it adds to uncertainty if all small parts should be sent out by helicopter when needed.

5.3.2 Recommended stock level

As mentioned there are several parameters that influence the stock level of spare parts. These parameters should be weighted differently, as some are more important than others. To be able to quantify the importance of each parameter the analytical hierarchy process were used. The thesis further proposes a scoring system, where each parameter is assigned a score from 1 to 3, based on the state of the parameter connected to the functional location or material. As an example is that functional locations with high failure consequences, is assigned the value 3. By using this system for determining spare part stock levels, the most important parameters are evaluated before deciding ROP.

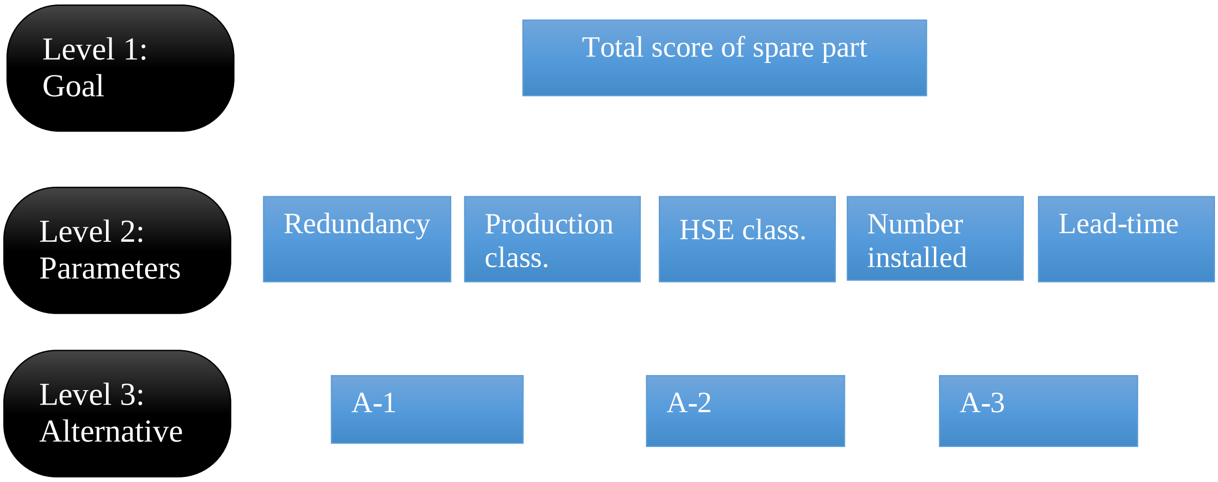
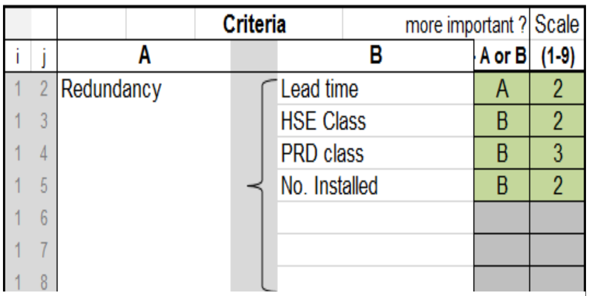


Figure 5-2 Analytical hierarchy process

The first level is the overall goal for the AHP, reaching a value that corresponds to the vital, essential or desirable criticality. The second level is the parameters criticality is based on. Level 3 is alternative values the parameters can have. To weigh parameters against each other, the AHP was used. The AHP process is based on pairwise comparisons. The pairwise comparisons was performed in an excel workbook made available by Goepel (2015).



		Criteria		more important ?	Scale
i	j	A	B	A or B	(1-9)
1	2	Redundancy	Lead time	A	2
1	3		HSE Class	B	2
1	4		PRD class	B	3
1	5		No. Installed	B	2
1	6				
1	7				
1	8				

Figure 5-3 Pairwise comparison , Screenshot from Goepel's (2015) workbook.

The workbook lets the user do the pairwise comparison of parameters by entering how important one is to the other. Figure 5-3 shows how the comparison is done. To the left is parameter A, redundancy, and to the left the four other parameters B. In the next column which of the two parameters is chosen, A or B. The last column to the right the relative importance is entered, how much more important one parameter is compared to the other. The scale goes ranges from 1 to 9. This is done in the same way until all parameters has been compared to each other, then a table showing the relative importance of the 5 parameters is automatically updated. The results of the comparison is shown in table 5-1:

Parameters	**Weight**
Failure consequence classification, HSE	0.25
Failure consequence classification, production	0.31
Redundancy of functional location	0.13
Lead time of spare	0.12
Number installed	0.19

Table 5-1 Weightage of spare part classification parameters.

Each parameter has three alternatives. These alternatives are values the parameters can hold, and are shown in the list below.

- Failure consequence classification (HSE and production)
  - High - Vital
  - Medium – Essential
  - Low - Desirable
- Redundancy
  - No redundancy - Vital
  - One parallel unit - Essential
  - Two or more parallel - Desirable
- Number installed
  - More than 10 - Vital
  - Between 2 and 10 - Essential
  - Only 1 - Desirable
- Lead time:
  - More than 90 days - Vital
  - Between 30 and 90 days - Essential
  - Less than 30 days – Desirable

Vital alternatives are assigned a score of 3, essential alternatives are assigned score 2, and desirable alternatives are assigned score 1. The total score of each spare part is calculated as

$$Total\ score = \frac{\sum Criteria\ weightage * Alternative\ score}{3}$$

This results in total scores ranging from 0 to 1. The total score serves as a percentage score, this means that 0-0,333 is characterized as desirable, 0,334-0,667 is characterized as essential and 0,668 – 1 is characterized as vital. To finally determine the recommended spare part level the total score is multiplied with expected consumption. The recommended stock level is equivalent to the ROP defined in SAP.

$$Recommended\ stock\ level = Total\ score * Expected\ yearly\ Consumption$$

The formula results in a percentage of the expected consumption on stock at all times. Because the stock level is based on consumption it reduces the possibility of overstocking, or ending up in a situation without the necessary spare parts.

There is a possibility that the expected yearly consumption is below 1, that will result in a recommended stock level of 0 according to the calculations. As it is already decided to stock the framework will then recommend a stock level of 1.

5.4 Repair process

In the thesis repairs are assumed to be instantaneous, resulting in MTTF=MTBF. An additional manual input of replacement time per part could have been introduced, but was found to be unreliable, as well as having little influence on the decision. Therefore the repair process was assumed to be an instantaneous process. The only function of a repair is to restore function as well as reducing the spare part stock. The reason for the assumption, is that the lead time is often much longer than the actual repair time. The inclusion of repair times will not improve the framework noteworthy, as the lead time for materials is generally much larger than actual repair times. To demonstrate the difference; lead times is often measured in days or weeks, while repair time is measured in hours.

5.5 Failure process

The life of a mechanical object is generally divided into three phases; burn-in phase, useful life, and wear-out phase. In the burn-in phase the failure probability is decreasing, close to constant in the useful life, and increasing in the wear-out phase. This can be visually expressed by the bath-tub curve, which often is claimed to be realistic for mechanical objects.

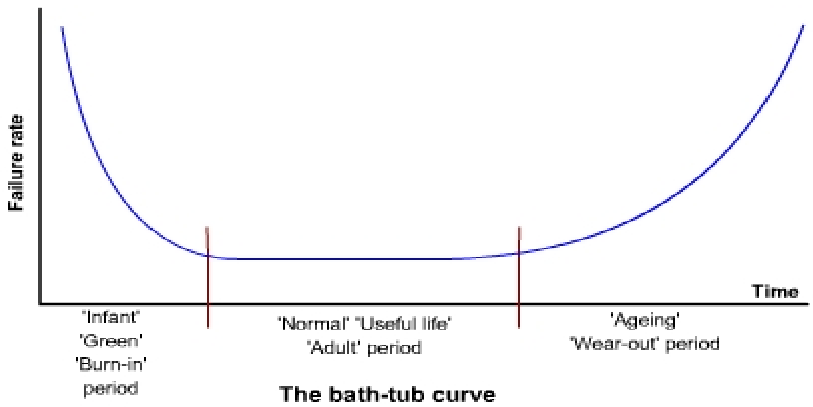


Figure 5-4 Bath-tub curve. (NPTEL, 2015)

Failures in the burn-in phase may be caused by quality problems of components, or installation problems. Quality problems may be removed by thorough quality testing before installation. In this thesis it has been assumed that quality and installation problems have been eliminated by proper testing and highly competent personnel. In this thesis it is assumed that the equipment is subject to maintenance which includes refurbishing or replacing components before the wear-out phase. These two assumptions makes it appropriate to use failure data published in OREDA (2009). “An important implication of the constant failure rate function is that an item is considered to be “as good as new” as long as it is functioning. All failures is are purely chance failures and independent of the age of the item.” (OREDA, 2009). In the thesis failure rates based on calendar time from OREDA was used. That gives a lower failure rate for most equipment, but this is the most accurate number, as operational time is rarely used, as well as failures can occur when equipment is not running.

5.5.1 Failure rate

Failure rates can be expressed by the exponential distribution with parameter λ. The exponential distribution can be applied since the failure rates are constant in the “useful life” period. The exponential distribution has probability density function, f(t) and expectation, E(t) (NPTEL, 2015):

$$f(t) = \lambda e^{-\lambda t} \; where \; \lambda = \frac{1}{MTTF}$$

$$E(t) = \frac{1}{\lambda} \; and \; Var(t) = \frac{1}{\lambda^2}$$

Where:

λ is the distribution parameter, in this case failure rate from OREDA.

t = time in hours

Based on the function reliability at time t, R(t), and probability of failure, F(t) can be calculated. That is the probability of the equipment does not fail until time t and is is given by

$$F(t) = \int_0^t e^{-\lambda t} dt = 1 - e^{-\lambda t}$$

$$R(t) = 1 - F(t) = 1 - \int_0^t e^{-\lambda t} dt = e^{-\lambda t}$$

In OREDA failure rate (λ) is given by failures per 1000000 hours. If the failure rate is 28 failures per 1000000 hours, this is equal to MTTF of 35714.3 $\left(\frac{1000000}{28}\right)$ hours per failure. The reliability after 5 years can be calculated as = 5*8760 = 43800 hours.

$$R(43800) = e^{-43800/35714,3} = 0,293$$

$$F(43800) = 1 - e^{-43800/35714,3} = 0,707$$

The exponential distribution is shown in figure 5-5. From the figure it can be seen that the reliability is decreasing over time, and failure probability is increasing over time. The failure probability function is used in the decision framework in the form "frm_DecisionAid".

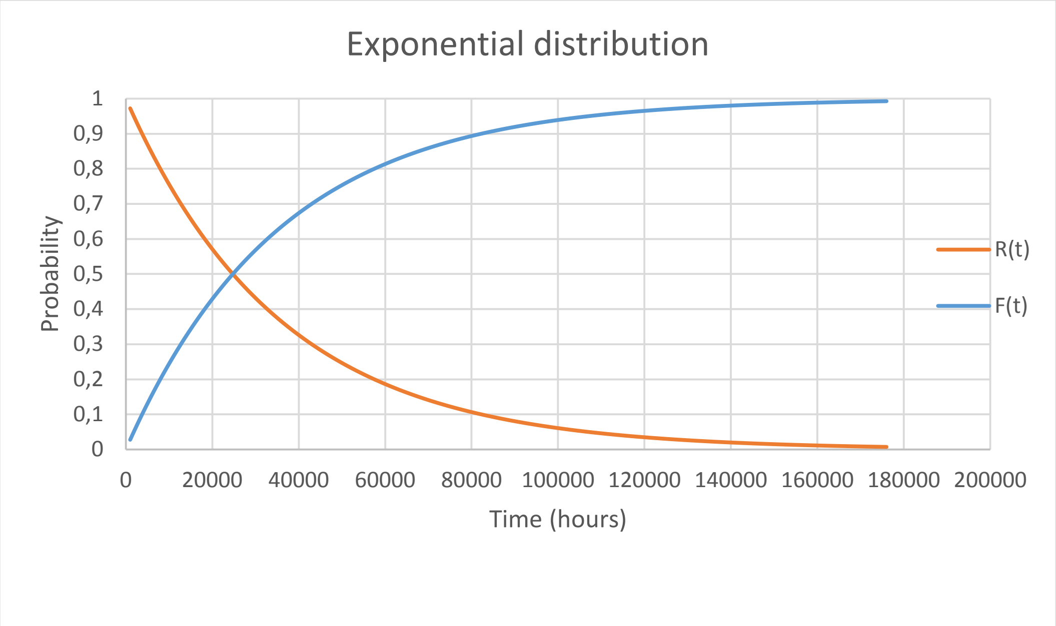


Figure 5-5 Failure and reliability probability distribution.

The reliability function can also be used backwards to calculate service intervals. If DD require a reliability of 97% at all times, the reliability can be set equal to 0.97 and calculate the t, or service interval.

$$R(t) = e^{-\lambda t} = 0.97$$

$$t = \frac{\ln(R(t))}{-\lambda} = \frac{\ln(0.97)}{-\frac{28}{1000000}} = 1087 hours \approx 45\ days.$$

This means that equipment with a failure rate of 28 failures/million hours, need service every 45 days to sustain a 97% reliability. This should be implemented in the RCM analysis, when deciding interval of PM tasks.

5.5.2 Failure during lead time

Many spare parts may be used several places. If only one spare is available, it will be used on the first failure if it is not a safety stock for a specific FL. In this situation, there is a possibility of a second failure causing a second demand for the same spare part that was used. The probability of a second failure during lead time can be useful to be aware of when determining if the stock levels. The probability can be calculated in the same way as the example above by replacing t= lifetime with t_L=lead time.

$$F(t_L) = 1 - e^{-\lambda t_L}$$
$$R(t_L) = e^{-\lambda t_L}$$

5.6 Data acquirement

In order to get as much input from the real world as possible the Access database was built with data already stored in SAP. The reason for building the database, is that it makes manipulation (comparisons of stock levels, showing overstock, etc.) of the data easy. Having the data stored orderly in tables, queries selecting only specific data for can be created. The framework is based on data available from SAP, such as attributes of material, equipment or functional location. Most of the data stored in SAP is easily accessible by exporting the data to Excel files. Excel files are highly compatible with Access, which made the data import quite easy. The data used as input to the database is explained in the next section. Most of the data in table 5-2 could be directly exported from SAP, except from “number installed”. The reason for this is that there is no attribute called “Number installed”. This issue was solved by creating one query to count BOMHeaders in the “tbl_Equipmentoverview” table, and one query to count BOMdetails in the table “tbl_BOMdetail”. The result of the counts was entered in table “tbl_Material” for each material as well as using the same queries in the forms, in case this number changes. As the recommended spare part stock level is influenced by how many times a material is installed, it is important that the user easily finds this information.

Another issue is that not all materials has a price. Only material types ZCON and ZSPR have prices in SAP. ZCPX materials are depreciated by Dolphin Drilling PTE Limited, in

Singapore, and are not accounted from the operation budget. Because of that situation the price field is a dropdown list, where a price can be chosen or entered, this way prices can be added when using the framework to make decisions.

Material	**Functional location**	**Equipment**	**Bill of materials**
Material number	Functional location ID	Equipment number	BOM Header
Material description	Functional location description	BOM header material	BOM detail
BOM Header/Detail	Redundancy		Quantity in BOM
Number installed	HSE classification		
Material type	Production classification		
Reorder point	Cost classification		
Maximum stock level	SFI group		
Planned delivery time	ABC indicator		
Moving price			
Number in stock			
MRP-type			
Manufacturer part number			
Quantity purchased			
Quantity consumed			

Table 5-2 Data required to build database in Microsoft Access

5.6.1 Explanation of attributes

Material number: All materials have its own unique number, this is generated when creating the material in SAP. Material number is a number consisting of 3-6 digits. With the material number, it is easy to look up what the material is, attributes of the material, where it is used, etc. The material number is important to use in the framework, in order to know which material is analyzed.

Material description: The description of a material. The description is limited to 40 characters. By including it in the database, it saves the user the time of looking up the material in SAP. Material descriptions should be standardized, by standardization fewer materials will be created because it will be easier to find the correct material. DD has potential for improving material descriptions, as many duplicate materials was found in the current situation analysis.

BOM header/detail: In the table "tbl_Material" there is a yes/no field to show whether or not materials is a BOMheader or a BOMdetail, if it is "yes" for BOMheader, it means that the material has a BOM. If the BOMdetail field is "yes" the material is part of a BOM. By having these yes/no fields, it is easy to see if the material is in a BOM, or is the header of the BOM. In the case of materials with "no" in both fields, the material can be used several places, and should be connected to a BOM. That means that not all BOMs are complete. All consumables have "no" in the fields, as consumables are not used in BOMs.

Number installed: This is the number of identical items installed throughout the MODU. The information is used when deciding reorder point and maximum stock level as well as evaluating the necessity of spares.

Material type: All materials are classified as capital spares (ZCPX), spare parts (ZSPR) or consumables (ZCON), this is the material type. The material type is useful for the current situation analysis.

Reorder point: The reorder point (ROP) says at what stock level materials are reordered. If the stock level is below the ROP, the material should be replenished. For example if a material has a ROP of 2, it should be reordered when there is 1 left in stock. ROPs is included to compare the presented framework results with the current situation.

Maximum stock level: MSL is the highest stock level that should be kept of a material. No materials should be stocked above the MSL. That will contribute to unnecessary large spare part inventory and tied up capital. As with reorder points, there is a possibility that many maximum stock levels can be adjusted down.

The ROP and MSL is set by the maintenance onshore team in collaboration with the offshore maintenance personnel. The collaboration ensures reasonable levels with regard to consumption.

Moving price: The price of the material. The price in SAP is an average price calculated from all the purchases of the specific material. This will be further used in analyses of inventory value.

MRP-type: This is explained in section 3.2, regarding spare parts.

Manufacturer's part number: This is the material number the manufacturer uses, for example a roller bearing has a material number 309141, and manufacturer part number H2RIE001036. When DD order the part they can refer to the manufacturer part number and be sure that they get the same bearing as last time it was ordered. The manufacturer part number is brought into the database because there is a possibility that several materials have the same manufacturer part number, which means that they are duplicate and inventory control gets more difficult.

Quantity purchased/consumed: How many of a material that is previously purchased and consumed/used. In the database a field for quantity purchased and quantity consumed is included. It then becomes available for comparison with ROPs and MSL. The consumption also gives an indication of consumption, which is important information when deciding stock levels.

Functional location ID: The functional location is the location where maintenance is performed. The object which serves a specific function, for example propulsion thruster unit number 1 has functional location 540-635-YR-1001. The consequence classification is done on a functional location level. Including functional locations is necessary for creating the technical hierarchy matching the hierarchy in SAP in the Access database. By including functional locations in the database it also becomes possible to sort functional locations by number of spare parts, overstock, or other information.

Functional location description: The description of functional location ID. See above example.

SFI: SFI coding is a coding system for main functions. In the case of the azimuth thruster, the SFI code is 635. It is included in the database to be able to sort for example costs under SFI codes. The SFI coding system is explained in detail in section 2.3.1.

ABC indicator: The ABC indicator is based on redundancy and functional location failure consequence classes; production, HSE and cost. For the functional locations having an ABC indicator of 1-9 it is based on the following: If the functional location has no redundancy the indicator and any of the three classes have high failure consequence the indicator is 3. If no redundancy and medium failure consequence, indicator is 2, no redundancy and low failure consequence gives indicator of 1. For functional locations with one parallel unit and high failure consequence in any class the indicator is 6, medium failure consequence and one parallel unit gives indicator 5, low failure consequence and one parallel unit gives indicator 4. The same logic goes for functional locations with two or more parallel units with an indicator from 9 to 7.

A	ABC indicator text
1	Consequence L, Red A
2	Consequence M, Red A
3	Consequence H, Red A
4	Consequence L, Red B
5	Consequence M, Red B
6	Consequence H, Red B
7	Consequence L, Red C
8	Consequence M, Red C
9	Consequence H, Red C
A	Administrative FL
N	Criticality N/A
Y	Crit. to be decided
Z	Crit. not defined

Figure 5-6: ABC indicator, as used in SAP.

For explanations on redundancy and classification see the consequence classification section 2.3.2.

Failure rate: The failure rate used in the framework is found in OREDA. Bolette Dolphin has only been in operation for approximately one year and there is therefore limited data with regards to failure rate. Sometimes redundancy effects failure rate, for example if there is two pumps running and one breaks down the stress increases on the other pump, such effects have been neglected in the framework. This is because it would require a separate study to find these effects, and the extra data would probably not improve the framework noteworthy.

5.6.2 Data not imported

Not all attributes of materials, equipment and functional locations were exported from SAP. In this section a selection of available attributes that were not included is discussed.

Area code: Most functional locations have a data field which says something about where on the rig or ship the functional location is located. It is built up as shown in figure 5-7. By referring to the code one can easily see where the functional is located. The coding could be used for sorting of materials, costs, etc. It was

Area Code

Part	D	Drilling/Moonpool Area
Element L1	C	Longitudinal Centre
Element L2	M	Midship
Element L3	XD	Drillfloor
Detail	DFCW	Drill Floor & Catwalk Machine
Area Code	DCMXD-DFCW	

Figure 5-7 Area code, screenshot from SAP

decided that the inclusion of area codes would not improve the framework noteworthy, as well as not all functional locations have data on the area code fields.

Performance Standards: Some functional locations have specific performance standards they have to follow. These are used for reporting incidents as well as having a specific standard the equipment has to be manufactured to, as well as having maintenance comprehensive enough to achieve the desired HSE level. Not all functional locations is connected to a specific performance standard, but typically safety critical elements (SCE) or well barriers etc. has these performance standards they have to follow. The performance standards are used mainly on the UKCS and is thus mainly applicable if the MODU is located on the UKCS.

Base unit of measure: All materials have a unit of measure, some materials are denoted as pieces, others as pairs, boxes, etc. It was decided not to include base unit of measure due to the fact that the information is not always correct. The information is mainly used for procurement, and it should be a simple task to figure out if the order should be 100 bolts or 100 boxes of bolts.

Material group: As all materials have their unique material number, materials can also be sorted in groups. Materials are assigned to material groups based on SFI groups, which means that the material groups are based on where materials are used, not what type of material it is. That makes the material groups misleading, as a specific material is not necessarily bound to a SFI group because many materials can be used several places. Because of this grouping it was decided not to further take advantage of material groups. Furthermore material groups are seldom used in practice, thus not giving any additional value to the framework. If it turns out that material groups are wanted, it is a simple task to provide the data at a later point.

Storage location: All materials has to be stored somewhere. Where a material is stored should be easily accessible for the maintenance personnel so they can find the material when they need it. For procurement purposes it is not that important, as storage costs is assumed to be fixed regardless of the storage location. Where parts should be stored is also an intuitive exercise, as it depends on where the rig is located, size of the part and other parameters.

Safety stock: Some spare parts has a safety stock, this depends on which equipment it is a spare part for, as well as the importance of the part. Some materials can be used as spare part for several equipment with varying importance. For some production critical equipment a safety stock is saved for use when a specific equipment fails, thus being able to restore functionality quicker than if the material has to be procured and waited for. In the framework costs of stocking a material and purchasing the material when required is displayed. If the costs of purchasing when required are very high, it should be evaluated to keep a safety stock.

Availability check: Some materials are more important or more used than others. This can be seen for example by the routines for availability checks. This is a routine for counting the storage locations and creating material requisitions if the stock is starting to get low. The availability check can be seen for all materials and is denoted by; 01, 02, CH, KP or Z1, depending on how often the materials are to be counted. The counting schedule are varies from daily to individual schedules. It was decided that the information regarding availability checks would not improve the framework.

5.6.3 Data export

The data connected to functional locations, equipment and materials are stored in SAP. In order to set up a database for this thesis, data was exported from SAP to Excel workbooks and imported these workbooks to Access. Both SAP transaction code SE16N and Winshuttle was used for data export. Winshuttle is an add-on program used for SAP data handling. SE16N lets the user export data to Excel. SAP transaction was used for direct export of attributes connected to materials, for example material numbers, description, BOMs, and so on.

The SE16N transaction front page is displayed in figure 5-8, here tables and restrictions for the export is chosen. In this case, table MARA – general material data and material type ZSPR is chosen. Other restrictions can also be entered, such as maximum no. of hits, who have created the materials, etc.

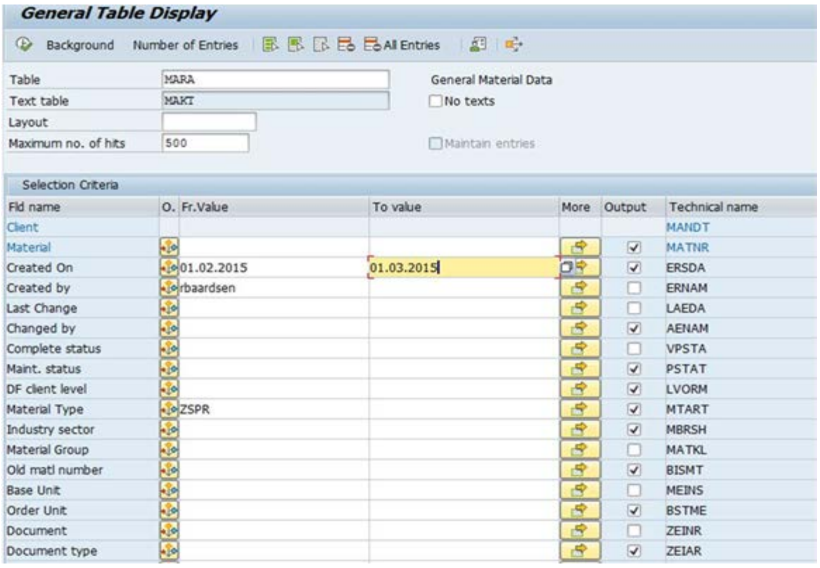
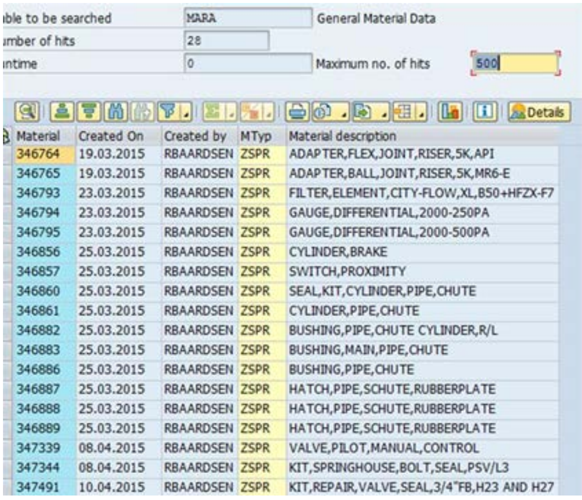


Figure 5-8 SE16N frontpage

A selection of the result of the search in figure 5-8 are shown in figure 5-9.



Material	Created On	Created by	MTyp	Material description
346764	19.03.2015	RBAARDSEN	ZSPR	ADAPTER,FLEX,JOINT,RISER,5K,API
346765	19.03.2015	RBAARDSEN	ZSPR	ADAPTER,BALL,JOINT,RISER,5K,MR6-E
346793	23.03.2015	RBAARDSEN	ZSPR	FILTER,ELEMENT,CITY-FLOW,XL,B50+HFZX-F7
346794	23.03.2015	RBAARDSEN	ZSPR	GAUGE,DIFFERENTIAL,2000-250PA
346795	23.03.2015	RBAARDSEN	ZSPR	GAUGE,DIFFERENTIAL,2000-500PA
346856	25.03.2015	RBAARDSEN	ZSPR	CYLINDER,BRAKE
346857	25.03.2015	RBAARDSEN	ZSPR	SWITCH,PROXIMITY
346860	25.03.2015	RBAARDSEN	ZSPR	SEAL,KIT,CYLINDER,PIPE,CHUTE
346861	25.03.2015	RBAARDSEN	ZSPR	CYLINDER,PIPE,CHUTE
346882	25.03.2015	RBAARDSEN	ZSPR	BUSHING,PIPE,CHUTE CYLINDER,R/L
346883	25.03.2015	RBAARDSEN	ZSPR	BUSHING,MAIN,PIPE,CHUTE
346886	25.03.2015	RBAARDSEN	ZSPR	BUSHING,PIPE,CHUTE
346887	25.03.2015	RBAARDSEN	ZSPR	HATCH,PIPE,SCHUTE,RUBBERPLATE
346888	25.03.2015	RBAARDSEN	ZSPR	HATCH,PIPE,SCHUTE,RUBBERPLATE
346889	25.03.2015	RBAARDSEN	ZSPR	HATCH,PIPE,SCHUTE,RUBBERPLATE
347339	08.04.2015	RBAARDSEN	ZSPR	VALVE,PILOT,MANUAL,CONTROL
347344	08.04.2015	RBAARDSEN	ZSPR	KIT,SPRINGHOUSE,BOLT,SEAL,PSV/L3
347491	10.04.2015	RBAARDSEN	ZSPR	KIT,REPAIR,VALVE,SEAL,3/4"FB,H23 AND H27

Figure 5-9 Results of SE16N transaction

By using the SE16N transaction for several tables, all materials, BOM lists, functional locations (except consequence classification), and equipment was exported. The export of functional location consequence classification was more complicated. The consequence classification is stored in different tables, and it was necessary to compile information from several tables into one excel sheet, for that export Winshuttle is better suited. The data export resulted in five Excel sheets.

- All functional locations and attributes and connected equipment
- Functional location consequence classification
- All equipment data and connected BOM header materials
- All BOM lists, with BOM header material and connected BOM detail material
- All materials and material attributes

These five excel sheets made up the basis tables for the database. The next section describes how the database was built.

5.7 Microsoft Access - Building the database

Microsoft Access is a database management system from Microsoft. It has a user friendly graphical user interface, and lets the user create a relational database. The Access database is made up of seven major components;

- Tables
- Relationships
- Queries
- Forms
- Reports
- Macros
- Modules

In the Access database, reports and modules were not used. All functions used in the thesis will be described in the following sections. When creating the tables in Access it is possible to import data easily as it is compatible with many file formats. Naming of tables, queries or forms, should start with “tbl_”, “qry_”, or “frm_” respectively, for easier referencing within the database. By following this principle it is easier for the user to understand the program flow.

In the thesis, the Access database has been used to find results, and to build the framework that is presented. Remember that the main objective was to find an efficient method of deciding whether or not to stock a spare part within the technical hierarchy. The database is found on the USB flash drive attached to the thesis.

5.7.1 Tables in Access

First attributes from SAP about materials, equipment, functional locations and BOMs was exported to Excel sheets. The Excel sheets was then imported to Access, making up the tables further referred to as basis tables (marked with an asterisk below). These tables contain all the information listed in table 5-2 and is the basis of the results from queries, calculations, etc. It is necessary with these tables to be able to set up the structure equal to the technical hierarchy. In total 8 tables is necessary for optimal use of the decision framework.

- tbl_FunctionalLocation*
- tbl_FLclassification*
- tbl_Equipmentoverview*
- tbl_BOMdetail*
- tbl_Material*
- tbl_ShoppingCart
- tbl_OverstockList
- tbl_SizeCharacteristics

In design view of tables the table is designed. The field names becomes column headers in the datasheet. The primary key is defined, the primary key is used to connect the table to other tables, when looking up information. It is decided what type of data the field contains, whether it is short text, numbers, yes/no, hyperlinks etc. In the database the datatypes used are short text, numbers and yes/no fields in the tables. When opening the datasheet view, data is clearly shown in a datasheet format, with material numbers to the left and all of the information to each material in columns.

Material

Field Name	Data Type
MaterialNumber	Number
BOMHeader	Yes/No
BOMDetail	Yes/No
MaterialDescription	Short Text
NumberInstalled	Number
MaterialType	Short Text
ReorderPoint	Number
MaximumStockLevel	Number
MaterialPrice	Number
OnStock	Number
MRPType	Short Text
ManufacturerPartNumber	Short Text
QuantityPurchased	Number
QuantityConsumed	Number
Deliverytime	Number

Figure 5-10 Design of the "tbl_Material" table

Material

MaterialNum	BOMHeader	BOMDeta	MaterialDescription	NumberIn:	MaterialType	ReorderPo	MaximumStc	MaterialPrice	OnStock	MRPType	Manufacture	QuantityPurc	QuantityCon
15721	No	No	PIPEWIPER,6 5/8X19",SPLIT TYPE	1	ZSPR	0	0	154	7	PD	20012883	18	-11
16937	No	No	RADIO,AIR BAND WALTER DITTEL FSG5 AERO	1	ZSPR	0	0	0	0	PD	FSG5AERO	0	C
17466	No	No	GASKET,RING,BX 151 S316	1	ZSPR	6	10	0	0	VB	BX151316	0	C
17492	No	No	GASKET, RING, BX-152	1	ZSPR	0	0	28	4	PD	BX152	4	C
17493	No	No	GASKET,RING,BX-154,SS316	1	ZSPR	0	0	39	6	PD	BX154	6	C
17494	No	No	GASKET,RING,BX-155,SS316	1	ZSPR	0	0	62	4	PD	BX155	4	C
17495	No	No	GASKET,RING,BX-164,SS316	1	ZSPR	2	4	402	4	VB	BX164	5	-1
17500	No	No	GASKET, RING, R24 S316	1	ZSPR	0	0	0	0	PD	R24S316	0	C
21134	No	No	PLATE, FLAT STEEL, 3MM X 1,25M X 2,5M	1	ZCON	0	0	0	0	ND	151015	12	C

Figure 5-11 Datasheet view of "tbl_material" table

Tables are connected to each other by relationships. There are three types of relationships:

- One to one, "Only include rows where the joined fields from both tables are equal"
- Many to one " Include all records from table1 and only those records from table2 where the joined fields are equal"
- One to many " Include all records from table2 and only those records from table1 where the joined fields are equal"

Figure 5-12 shows the relationships, and what information that is stored in which table, in the database. Relationships prevent redundant data, meaning data is only stored one place. All information about functional locations, materials, BOMs could have stored in one table, but that would increase the size of the table as well as making it difficult to update. Because then data has to be updated multiple places. The “tbl_FunctionalLocation” table is related to both “tbl_FLclassification” and “tbl_Equipmentoverview”. This is because these two tables contain different information, as shown underneath the title of each table. The relationship from “tbl_FunctionalLocation” down to “tbl_Material” is the same relationship as the technical hierarchy in SAP. The reason for these relationships is that materials are used for specific places. The relationships are type many-to-many relationships, this is because one material can be connected to many functional locations, and one functional location may have many materials.

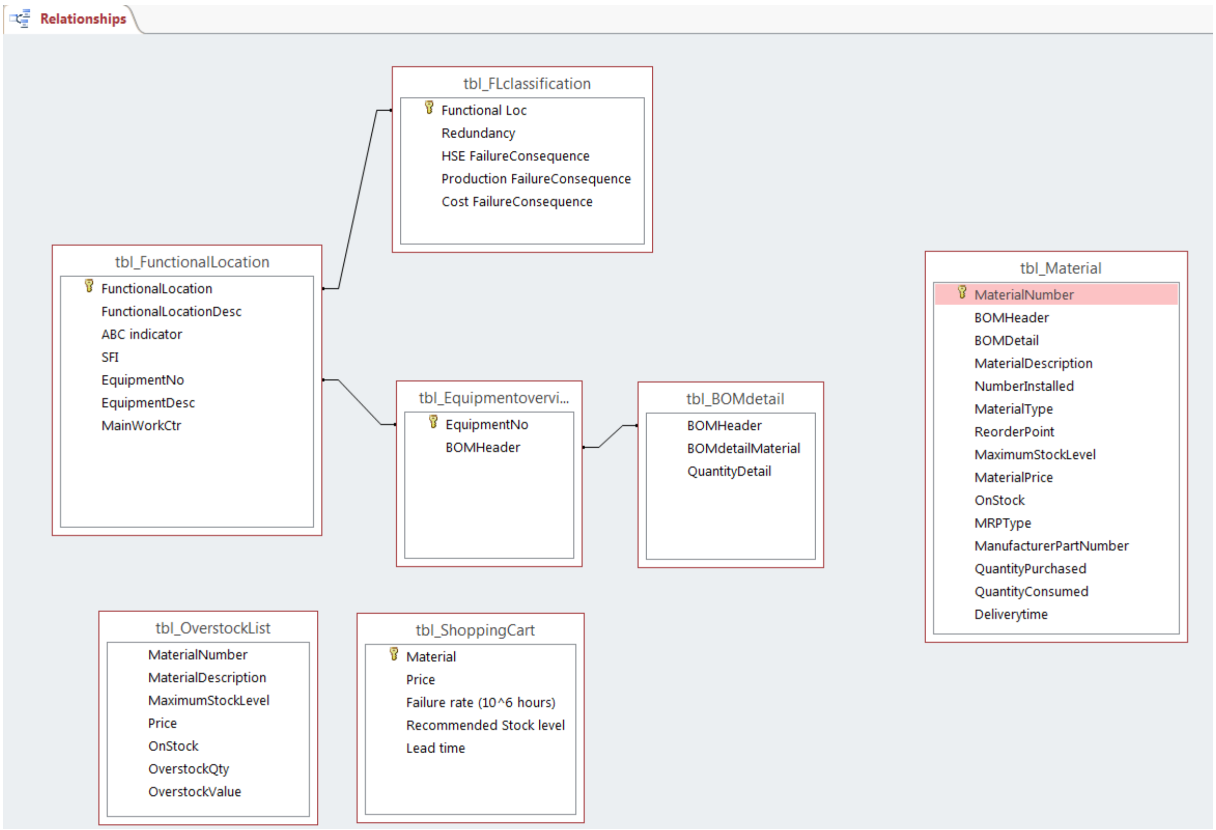


Figure 5-12 Relationships between tables in database. Screenshot from Microsoft Access

Building of the database started with only basis tables, because this is all the input data. To create functional forms (further explained in section 5.7.3), three more tables was necessary. “tbl_ShoppingCart”, “tbl_OverstockList”, “tbl_SizeCharacteristics”

The results from form “frm_DecisionAid” is stored in the table “tbl_ShoppingCart”. That makes it easy to export the results from Access to an Excel sheet, for sharing results, or other purposes. “tbl_ShoppingCart” stores data from two forms, “frm_DecisionAid”, and “frm_DecideSpareQuantity”, the data stored from the two forms are listed below.

- From “frm_DecisionAid “
  - Material number
  - Price
  - Failure rate
  - Lead time
- From “frm_DecideSpareQuantity”
  - Recommended stock level

The table “tbl_OverstockList”, stores the results from the form “frm_Overstock”. This serves the same purpose as “tbl_ShoppingCart”, sharing the information with others. The overstock lists are shown in form “frm_Overstock”, this contains a list of all materials that have larger on stock quantities than the current maximum stock level.

The table “tbl_SizeCharacteristics” is used to store information regarding holding costs and logistics costs depend on the size of the material. By storing the information in this table, it is easy to change later, if it changes. The holding and logistics costs are further calculated in the form “frm_DecisionAid”.

5.7.2 Queries in Access

What is a query?

> *A query is a request for data results, for action on data, or for both. You can use a query to answer a simple question, to perform calculations, to combine data from different tables, or even to add, change, or delete table data. Queries that you use to retrieve data from a table or to make calculations are called select queries. Queries that add, change, or delete data are called action queries. You can also use a query to supply data for a form or report. In a well-designed database, the data that you want to present by using a form or report is often located in several different tables. By using a query, you can assemble the data that you want to use before you design your form or report. (support.office.com, 2015)*

When setting up queries it is important that the tables are related to each other, if they are not, the results will show all data included in the tables, instead of the data that are connected to each other.

In the framework mostly select queries are used, which selects and show this data in a datasheet format depending on the design of the query. Figure 5-13 is an example of a query that shows all functional locations with a BOM, as well as showing the BOM.

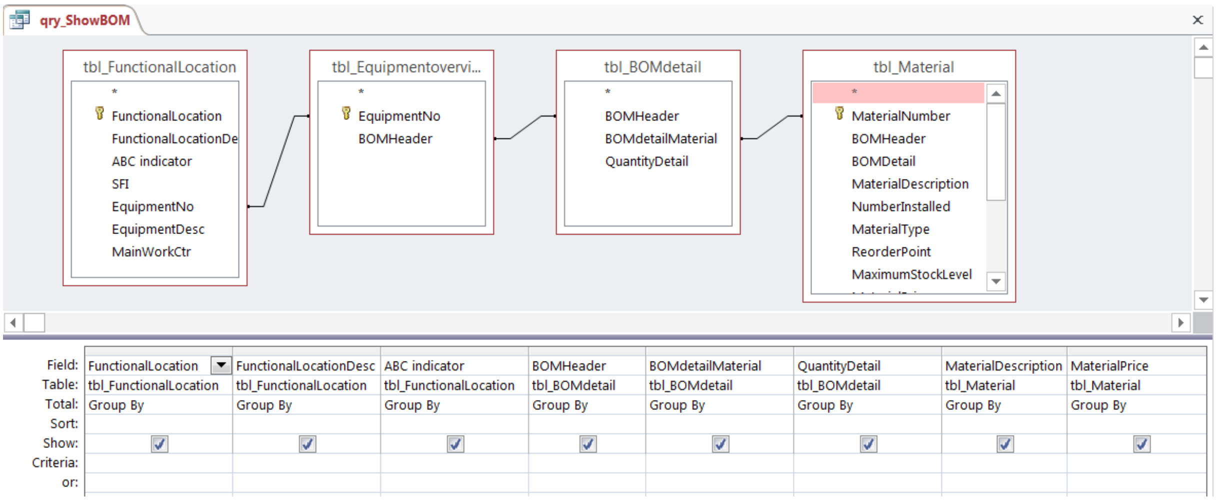


Figure 5-13 Design view of "qry_ShowBOM" query

In the grey field tables and relationships between tables are defined. As seen in the query, there are relationships from the functional location to the material number via two tables. In order to set up these relationships there must be fields with matching numbers or text. It can be seen from the figure that equipment number connects the two tables "tbl_FunctionalLocation" and "tbl_EquipmentOverview". BOMHeader connects the tables "tbl_Equipmentoverview" and "tbl_BOMdetail", and so on. In the bottom row there is a check box, by checking this box the field is included in the results. This lets the user add criteria to fields without showing the field in the results. As an example, the query in figure 5-13 only displays BOMs of functional locations with the ABC indicator "3", this is a criteria in the "ABC indicator" field in figure 5-13. How the results are sorted can be chosen in the "sort" row. Figure 5-14 shows the result of the "qry_ShowBOM" query. The query displays all the spare parts connected to functional locations. Only functional locations with ABC indicator 3 is included in the results, because of the defined criteria.

FunctionalLocation	FunctionalLocationDesc	BOMH	BOMdetailMaterial	MaterialDescription	MaterialPrice
540-303-LB-0110A	Block, Travelling, Main	321676	246631	RING,SNAP	271
540-303-LB-0110A	Block, Travelling, Main	321676	303729	SHAFT	0
540-303-LB-0110A	Block, Travelling, Main	321676	303730	SHAFT,ASSEMBLY,14" DIA	0
540-303-LB-0110A	Block, Travelling, Main	321676	303731	PIN,BECKET,8"	0
540-303-LB-0110A	Block, Travelling, Main	321676	303732	BEARING,ASSEMBLY	4533
540-303-LB-0110A	Block, Travelling, Main	321676	303733	SEAL	159
540-303-LB-0110A	Block, Travelling, Main	321676	303734	NUT,LOCK	55
540-303-LB-0110A	Block, Travelling, Main	321676	303735	WASHER,LOCK	17
540-303-LB-0110A	Block, Travelling, Main	321676	303736	NUT,LOCK	920
540-303-LB-0110A	Block, Travelling, Main	321676	303737	WASHER,LOCK	269
540-303-LB-0110A	Block, Travelling, Main	321676	303738	SHAFT	0
540-303-LB-0110B	Block, Travelling, Aux	321612	300425	SHEAVE,ASSEMBLEY	0

Figure 5-14 Result of "qry_ShowBOM" query

In the database there are 15 queries;

- qryAppendShoppingCart
- qry_AppendShoppingCartManual
- qry_AppendOverstock_All
- qry_AppendOverstock_qtysort
- qry_AppendOverstock_Valuesort
- qry_EmptyOverstockList
- qry_FL_DecisionAid
- qry_NoInstDetailMaterial
- qry_NoInstHeaderMaterial
- qry_Overstock_FLsorted
- qry_OverstockValue
- qry_OverstockValueTotal
- qry_ValueofBOM
- qry_ShowBOM
- qry_UpdateQtyShoppingCart
- qry_ShoppingCart_vs_ActualStock

All these queries have different functions and are used by forms or by themselves in the current situation analysis. All queries will be described under its own section. The design and SQL of all queries are given in Appendix D.

5.7.2.1 qry_AppendShoppingCart

This is a query that appends selected data to the table “tbl_ShoppingCart”. The data appended is material number, price, lead time and failure rate from the form “frm_DecisionAid”. In the form there is a button that runs this query, meaning the selected data will be added to the table. In the form “frm_DecisionAid”, the decision whether or not to stock a material is done (the form will be described in section 5.7.3.1). If it is decided to stock the item, the data is added to the table “tbl_ShoppingCart” by clicking a button. This way many materials can be analyzed and saved to a separate table to store the results.

5.7.2.2 qry_AppendShoppingCartManual

This query also appends data to a table. The query is run from the form “frm_DecideSpareQuantityManual” and appends the data; material number, price, lead time, failure rate, and recommended stock level to the table “tbl_ShoppingCart”, at the click of a button on the form. This query is similar to “qry_AppendShoppingCart”, but also includes recommended stock level. The reason for that is because the form “frm_DecideSpareQuantityManual”, enables the user to evaluate a recommended stock level without using the form “frm_DecisionAid”. The difference of the forms are further explained in section 5.7.3.

5.7.2.3 qry_AppendOverstock_qtysort, qry_AppendOverstock_Valuesort, qry_AppendOverstock_All

These three queries are designed to add overstock materials to the table “tbl_OverstockList”. The reason for three queries is that one query are not able to do three different functions. To make it easy for the user of the form “frm_Overstock”, each of these queries are run by the click of a button. The queries adds Material number, description, maximum stock level, price, on stock, overstock quantity, and overstock value to the table. This table can then be exported from Access to an Excel sheet which can be distributed. “qry_AppendOverstock_qtysort” adds the top 25 results sorted by overstock quantity, “qry_appendOverstock_valuesort” adds the top 25 results sorted by overstock value, and “qry_AppendOverstockAll”, adds all overstock materials to the table.

5.7.2.4 qry_EmptyOverstockList

This query is used in the form “frm_Overstock”. The function of the query is to delete all records from the table “tbl_OverstockList” and is run by pressing the button “Empty overstock table” in the form “frm_Overstock”. The reason for creating this query is to make it simpler to delete the records appended earlier. If DD would like to create a report of all overstock materials every month, it would be as easy as opening the form “frm_Overstock” and pressing the button “Empty overstock table”, and then append the new overstock list to the same table.

5.7.2.5 qry_FL_DecisionAid

This query is used in the form “frm_DecisionAid”, when selecting functional location to analyze. The query is designed to find functional locations from the “qry_ShowBOM”, that has found all functional locations with BOMs. “qry_FL_DecisionAid”all allows the user to filter the list of functional locations when using the form. That enhances the functionality of the form, by making it easier to find a specific functional location from the dropdown list. The filter is applied by the criteria on the fields FunctionalLocation and FunctionalLocationDesc as seen in figure 5-15. In the FunctionalLocation field, the criteria is “Like [Forms]![frm_decisionaid]![FLsearch]”, which returns only functional locations that contains the value in the field “FLsearch” in the form. The criteria in FunctionalLocationDesc is “Like [Forms]![frm_decisionaid]![DescSearch]”, which returns functional locations containing the text in the field “DescSearch” in the form.

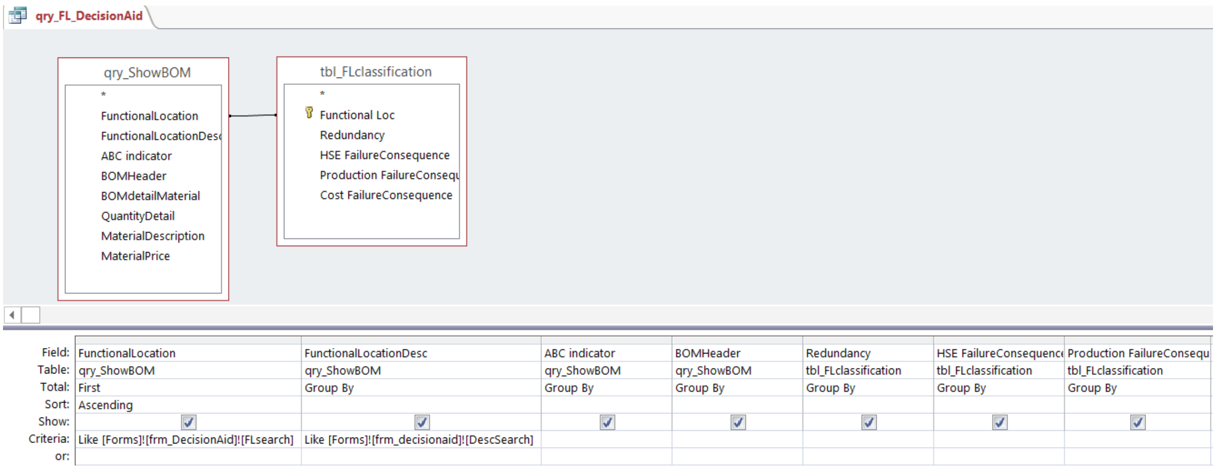


Figure 5-15 Design view of "qry_FL_DecisionAid"

5.7.2.6 qry_NoInstDetailMaterial and qry_NoInstHeaderMaterial

These two queries are used together to count how many times a material is installed on the MODU, and the result of the queries are found when selecting value for number installed in the form "frm_DecideSpareQuantity". "qry_NoInstDetailMaterial" counts how many BOMs a material is used in and "qry_NoInstHeaderMaterial", is used to count how many equipment a BOMHeader is connected to". In the form "frm_DecideSpareQuantity" these two queries are combined to a union query, which means both are run, to find out how many times a material is used on the MODU. Both queries have the same design as shown in figure 5-16. In the material field, there is a criteria that tells the query to only count number of occurrences of the material chosen in the "InputM" field in the form "frm_DecideSpareQuantity"

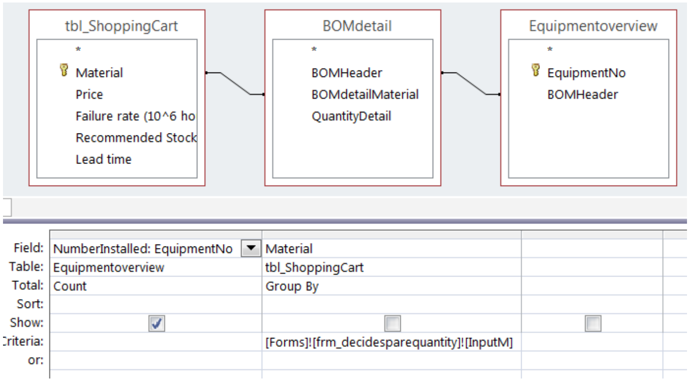


Figure 5-16 Design view of "qry_NoInstDetailMaterial"

5.7.2.7 qry_Overstock_FLsorted

This query is a select query which shows number of spare parts in the BOM, sum of BOM, sum of overstock quantity, and sum of overstock value sorted by functional locations. The query only selects functional locations with overstock value higher than 0. The query gives an overview of which functional locations with overstocked spare part inventories, and the value of the overstock inventory. The query is not connected to any forms, but can be used to give the user an idea about the stock levels of functional locations.

qry_Overstock_FLsorted

FunctionalLocation	FunctionalLocationDesc	BOMHeader	No of spare parts in BOM	BOMPrice	OverstockQty	OverstockValue
540-304-VP-0512	Gas Bottle. No.9, Crown Mounted Comp.	329113	4	2507	8	7696
540-304-YD-0500	Compensator, Crown Mounted	321618	124	157328	63	7972
540-311-EC-0001	Drilling Flight Recorder Server Rack	329242	12	94869	12	67095
540-311-EC-0101	DCI Main	327746	27	19272	75	7895
540-311-IB-0001	Cabinet, Control DCDA LER	327747	38	81771	39	67254

Figure 5-17 Datasheet view of "qry_overstock_FLsorted" query.

5.7.2.8 qry_OverstockValue

This query selects all materials that are overstock, and shows the overstock value. The query is connected to the form "frm_Overstock" and displays the results in that form. It looks up all materials with a stock quantity higher than the defined maximum stock level. Only materials with MRP type VB is included because only VB-materials has defined maximum stock levels. If that criteria is not used, the results would be misleading as very few PD- and ND-materials have defined MSLs. Figure 5-18 is a screenshot showing criteria for this query.

Field:	MaterialDescription	MaximumStockLevel	Price: MaterialPrice	OnStock	OverstockQty: ([onstock]-[maximumstocklevel])	OverstockValue: (([Onstock]-[maximumstocklevel])*[materialpr	MRPType
Table:	tbl_Material	tbl_Material	tbl_Material	tbl_Material			tbl_Material
Total:	Group By	Group By	Group By	Group By	Expression	Expression	Group By
Sort:						Descending	
Show:	✓	✓	✓	✓	✓	✓	☐
Criteria:			>=Val([Forms]![frm_Overstock]![fltPrice])	>[maximumstocklevel]	>=Val([Forms]![frm_Overstock]![fltQTY])	>=Val(([Forms]![frm_Overstock]![fltvalue]))	"VB"
or:							

Figure 5-18 Design view of qry_overstockValue , the query also shows material number.

5.7.2.9 qry_OverstockValueTotal

This query sums the overstock value for all results in "qry_OverstockValue". This query was used in the current situation analysis, in order to get the total sum of overstock materials. The reason for creating the query is that it is not possible to get both the total sum of overstock value, and the overstock value for each individual material in the same datasheet.

5.7.2.10 qry_ShowBOM

This query shows functional locations and the entire BOM, as well as prices of the BOM detail materials. The query only results functional locations which has a BOMs, which is used in "frm_DecisionAid" (which will be described in section 5.7.3.1). The query has the same relationships as the technical hierarchy in SAP. As seen in figure 5-19 the query shows quite much information.

FunctionalLocation	FunctionalLocationDesc	ABC indicato	BOMH	BOMdetailMaterial	QuantityDet	MaterialDescription	MaterialPrice
540-289-EC-0001	Panel, Control Mgps Aft. Aft Pmp Rm No.1	2	329002	312796	1	ANODE,CUPORLINE,SIZE DIA 130 X L 680MM	1695
540-289-EC-0001	Panel, Control Mgps Aft. Aft Pmp Rm No.1	2	329002	312797	1	ANODE,ALOLINE,SIZE DIA 130 X L 550MM	349
540-289-EC-0001	Panel, Control Mgps Aft. Aft Pmp Rm No.1	2	329002	312801	1	PANEL,CONTROL,MGPS,8A X 4 WAY	2131
540-289-EC-0001	Panel, Control Mgps Aft. Aft Pmp Rm No.1	2	329002	312802	1	FUSE,5A	2

Figure 5-19 Datasheet view of query "qry_ShowBOM".

5.7.2.11 qry_ValueofBOM

This query sums the value of all materials in the BOM connected to each functional location. It also shows the price of the BOM header. The query is used in "frm_DecisionAid", that way the price of the BOM header and the price of the complete BOM can easily be compared. This comes in handy because sometimes the price of individual parts are close to a complete assembly, and it is cheaper and quicker to change the assembly instead of components. For example for valves the price of seat, disc, actuator, etc. is sometimes more expensive to buy separately instead of purchasing the complete valve, an additional advantage is that it is less time consuming to replace a complete valve than components.

FunctionalLocation	FunctionalLocationDesc	BOMHeader	CountOfBOMdeta	BOMHeaderPrice	SumOfMaterialPrice
540-651-03-LIN-B6	Liner, M.E. No.3, B6	309602	9	1600	1423
540-651-03-LIN-B7	Liner, M.E. No.3, B7	309602	9	1600	1423
540-651-03-LIN-B8	Liner, M.E. No.3, B8	309602	9	1600	1423
540-651-03-PIST-A1	Piston, M.E. No.3, A1	309628	11	4155	5435
540-651-03-PIST-A2	Piston, M.E. No.3, A2	309628	11	4155	5435

Figure 5-20 Datasheet view of query "qry_ValueofBOM"

5.7.2.12 qry_UpdateQtyShoppingCart

This is a query used in the form "frm_DecideSpareQuantity". The query is used to update the quantity field in table "tbl_ShoppingCart". How it works is that it finds the selected material in "tbl_ShoppingCart" and adds the value in chosen stock level field in the form. This way the user does not have to manually enter the quantity in the table after deciding the stock level of a material.

5.7.2.13 qry_ShoppingCart_vs_ActualStock

For easy comparison of the results of the framework and the current situation, the query "qry_ShoppingCart_vs_ActualStock" can be used. The query selects materials from "tbl_ShoppingCart" and displays current information, such as current stock level, ROP and MSL. By using the form it is easy to create a table of all materials from "tbl_ShoppingCart" and compare the results from the framework with the current stock levels. Figure 5-21 displays the datasheet view of the query.

qry_Shoppingcart_vs_actualstock

Material	MaterialDescription	Price	Recommende	RecStvalue	OnstockValu	OnStock	ReorderPoin	MaximumStc
311654	FILTER,SERVICE,KIT,FOR,TMC105235	1884	2	3768	13188	7	0	0

Figure 5-21 Datasheetview of "qry_ShoppingCart_vs_ActualStock"

5.7.3 Forms in Access

What are forms?

> *Forms are like display cases in stores that make it easier to view or get the items that you want. Since forms are objects through which you or other users can add, edit, or display the data stored in your Access database, the design of your form is an important aspect. If you database is going to be used by multiple users, well-designed forms is essential for efficiency and data entry accuracy. (Office support, 2015)*

The Access database has five forms, these shows the result and performs the calculations of the framework. Forms is a clear way of showing data from tables and queries, as well as performing calculations. The forms in the Access database are used to; decide whether or not to stock a spare part, recommend stock level of spare parts, and show overstock materials. The forms are made of combinations of data already stored in the database and manual input. Using forms as the framework, makes it easy accessible for users without database experience, as the function of forms are intuitive. The forms will be described under its own section and are named:

- Frm_DecisionAid
- Frm_DecideSpareQuantity
- Frm_DecideSpareQuantityManual
- Frm_Overstock
- Frm_OverstockSubform

5.7.3.1 Frm_DecisionAid

Figure 5-22 is a screenshot of the blank form from Access. This form is designed to help the user make a decision of buying a spare part or not. It does so by calculating costs of stocking and stocking at failure, as explained in section 5.2. Then the user can easily compare the values and make a decision based on the costs, and failure probability.

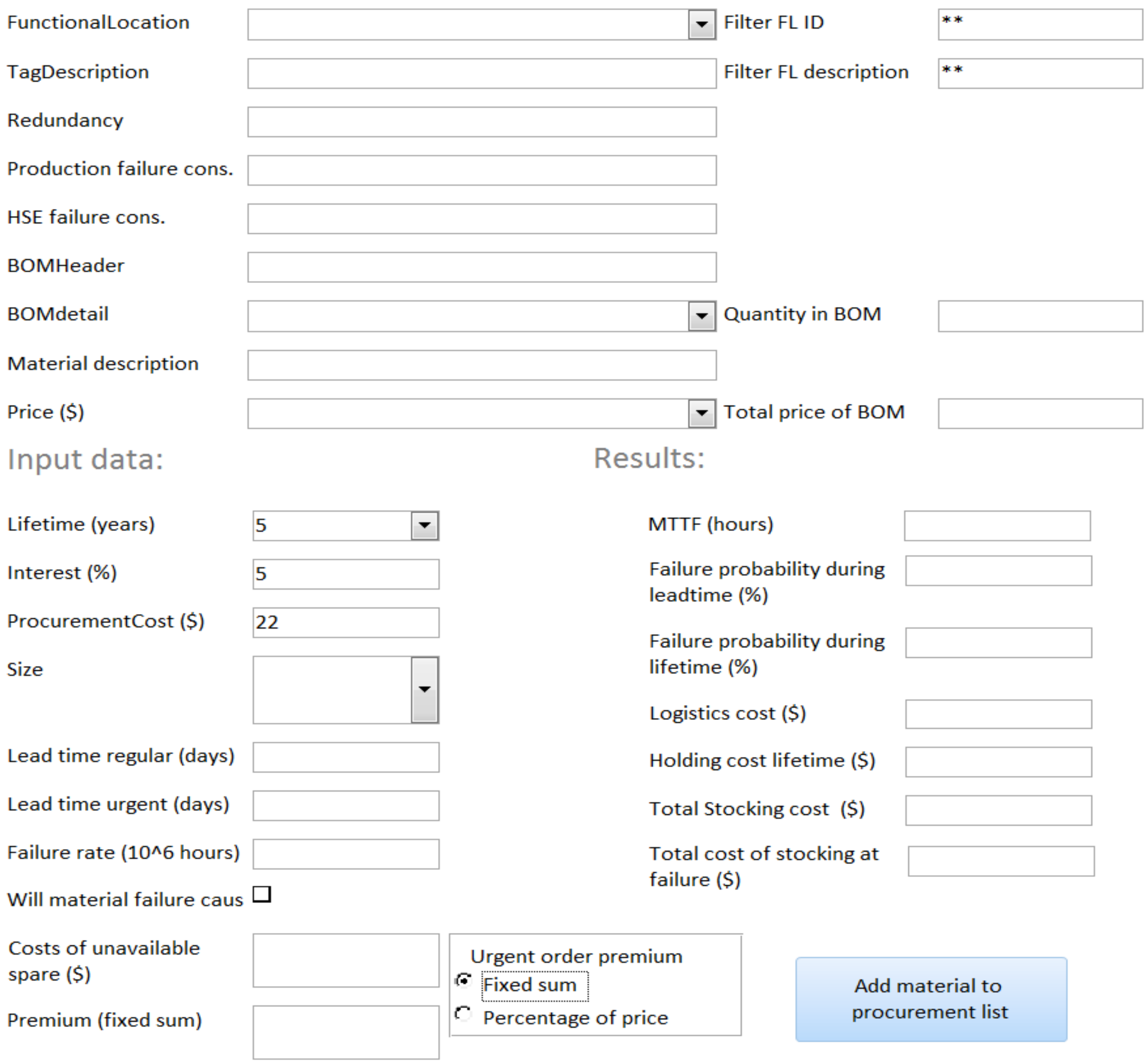


Figure 5-22 Form view of "frm_DecisionAid"

Choosing functional location and material

Figure 5-22 shows the form “frm_decisionaid”, it is a combination of dropdown lists and textboxes. In the functional location dropdown list the user may scroll through all functional locations, or use the filter to the right, either for FL ID or description. By writing between the **, the FL list will automatically filter results in the list to match the filter. When a FL is chosen redundancy, ABC indicator, BOM header, total price of BOM will automatically be updated based on the results of the “qry_ShowBOM” query. Then the user are able to select a BOMdetail material in the BOM to analyze. When choosing the dropdown list BOM detail, all items in the BOM appear with material number and description. Because not all materials have a price in SAP, the price box does not update automatically. But the price from the material table is loaded as a choice in the drop down list, it is also possible to input the correct price manually.

Input data

To calculate the total costs of materials, the form requires more data than SAP can provide in order to calculate costs of materials. These are listed under the input column.

Lifetime can be chosen from a list; 5, 10, 15 or 20. The default value is 5 years, other values can also be used. The lifetime is referred to as the lifetime of the functional location before an overhaul, for example a complete mud pump.

Interest is set to a default value of 5%, but may be changed manually. Interest is used to calculate tied capital cost.

Procurement cost is default $22 according to the calculation in section 5.2.2.2, the value can be changed if assumptions change.

The size field is a drop down list with values; large, medium, and small. This influences logistics and holding cost as explained in section 5.2.2.3 and 5.2.2.1, the percentages are stored in the table "characteristics", this way these may be changed easily if assumptions change.

Lead time (days) is set as an input value as the data in SAP was entered generically as 70 days for all materials. Because it is known that the lead time is wrong in SAP the form is set up for manual input of the lead time.

Failure rate: As the failure rate data in SAP is scarce, failure rates must be found in OREDA. When the MODU has been in operation for some years, data from SAP may be used to a larger degree. The failure rates in OREDA is given in failures per million hours, both calendar time and operational time. For some equipment it is most realistic to use calendar time, and other it is most realistic to use operational time, this depends on the equipment. In the calculations calendar time was used because this number is more reliable as data collection of operational hours for equipment that is only used for some time and turned off is generally poor. The failure rate is used to calculate MTTF, this is a number which is more intuitive. That is why it is included as a result, then the user can "get a feel" how long one can expect equipment to run before failure. If failure rates of the material is available, this should be used, otherwise the failure rate of the functional location can be used.

MTTF (hours) is used to calculate failure probability. The MTTF is directly calculated (as MTTF= 1000000/Failure rate) when the failure rate is entered. MTTF is further used to calculate failure probability during lifetime and lead time.

Failure probability during lifetime is calculated as

$$F(t) = (1 - Exp((-\frac{1}{MTTF} * Lifetime * 8760)) * 100)$$

This is under the assumption that material failure process have an exponential distribution. This value is automatically calculated as the user inputs failure rate. The failure probability is the probability that the component fails during the lifetime of the functional location, which is chosen manually.

Failure probability during lead time is calculated to show the probability of a second failure while waiting on the stock to replenish after the first failure. This is based on the assumption that the spare part was on stock before the first failure and is used to recover function after failure.

Will material failure cause downtime? This checkbox refers to the component failure, if the single component (BOM detail material) chosen can lead to operational downtime. There are some dependencies attached to this checkbox. The result of a checked box is:

- The box below will show “Day rate ($)
- The box underneath “Total stocking cost ($) will display “Total cost of stocking at failure ($)”
- Value of “Cost of stocking at failure ($) is

$$= Price + \frac{F(t)}{100} * ((Day\ rate * urgent\ lead\ time) + Premium)$$

If the checkbox is unchecked the form will show:

- The box below will show “Costs of unavailable spare ($)”
- The box underneath “Total stocking cost ($)” will display “Cost of stocking at failure ($)”
- Value of “Cost of stocking at failure” is

$$= Price + \frac{F(t)}{100} * (Costs\ of\ unavailable\ spare + premium)$$

Premium is either calculated as a fixed sum, or a percentage of the price. The premium can also be 0, if there is no premium for urgent orders.

Costs of unavailable spare / Day rate: This input value decides which value that is used in the calculation of “Total cost of stocking at failure” depending on the checkbox. The costs of unavailable spare might be many, for example increased operational cost of the redundant equipment, or more wear causing need for more maintenance. Day rate is the lost income due to stop in operation.

Urgent order premium: When making an urgent order, the supplier often demands a price premium for faster delivery. This premium is given either in a percentage of material price, or as a fixed sum. In the form, the user can choose between these two options. When choosing a field for entering the premium appears. The premium is used in the calculation of total cost of stocking at failure.

Results

Logistics cost is calculated as the percentage given in the characteristics table. The costs are 5%, 2% and 1% of the material price for respectively large, medium, or small materials.

Holding cost lifetime is the sum of tied capital cost and storage costs. The calculation of this is based on the input of interest, and size. The equations of these expenses are described in section 5.2.2.

Total stocking cost is the sum of holding cost, procurement cost, logistics cost and price of the material.

Total cost of stocking at failure is the cost of purchasing a part when it is required. This cost is calculated differently depending on the checkbox, as explained above.

When all fields are filled out it is easy to compare the expected expenses on the right side. Then the decision whether to stock or not can be taken. If the decision is to stock the material it can be added to the table “tbl_shoppingcart”. When it is added to the table the next material can be chosen for analysis. The advantages of having a separate table which all materials are added to, is that it is easy to look up materials previously analyzed as well as data are stored for the form where quantity to stock is chosen (“frm_DecideSpareQuantity”).

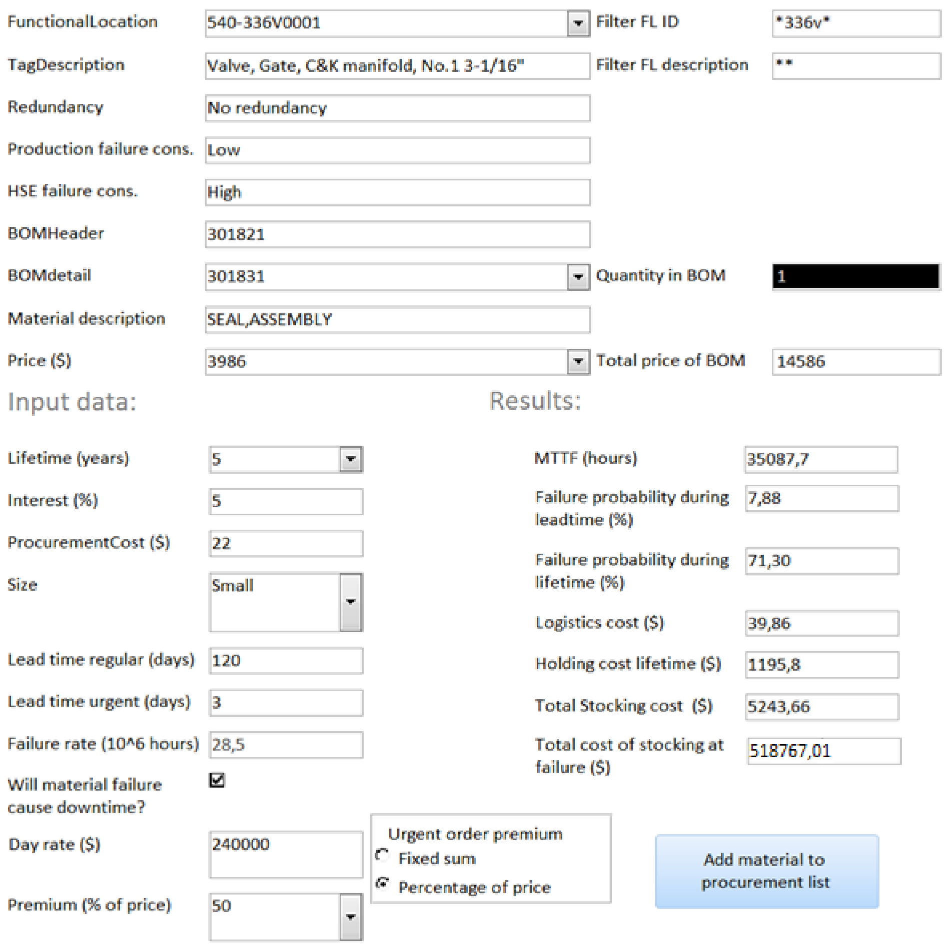


Figure 5-23 Complete DecisionAid form . In this example the stocking at failure is higher than stocking cost. That leads to the decision to stock this material.

5.7.3.2 Frm_DecideSpareQuantity

This form is used to decide how many of each spare part to initially stock. This form is to a higher degree automatized than “frm_ DecisionAid”. This is because all data this form already exist or is entered in the form “frm_DecisionAid”. The layout of the form is shown in figure 5-24. In form view, which is the view that allow interaction with the form, the two tables “weightage” and “scores” are hidden. The weightage table is used as input to how much each parameter is weighted in the calculation of “recommended stock”. The weightage is described in detail in section 5.3, and the results is input in this form and used for all material stock decisions. It is important that these weightages are not changed from material to material as it would make the basis of each decision different. The “score” table is hidden as it has no value for the user, as it is only used in the calculation of recommended stock. The background for the scoring system is also described in section 5.3.

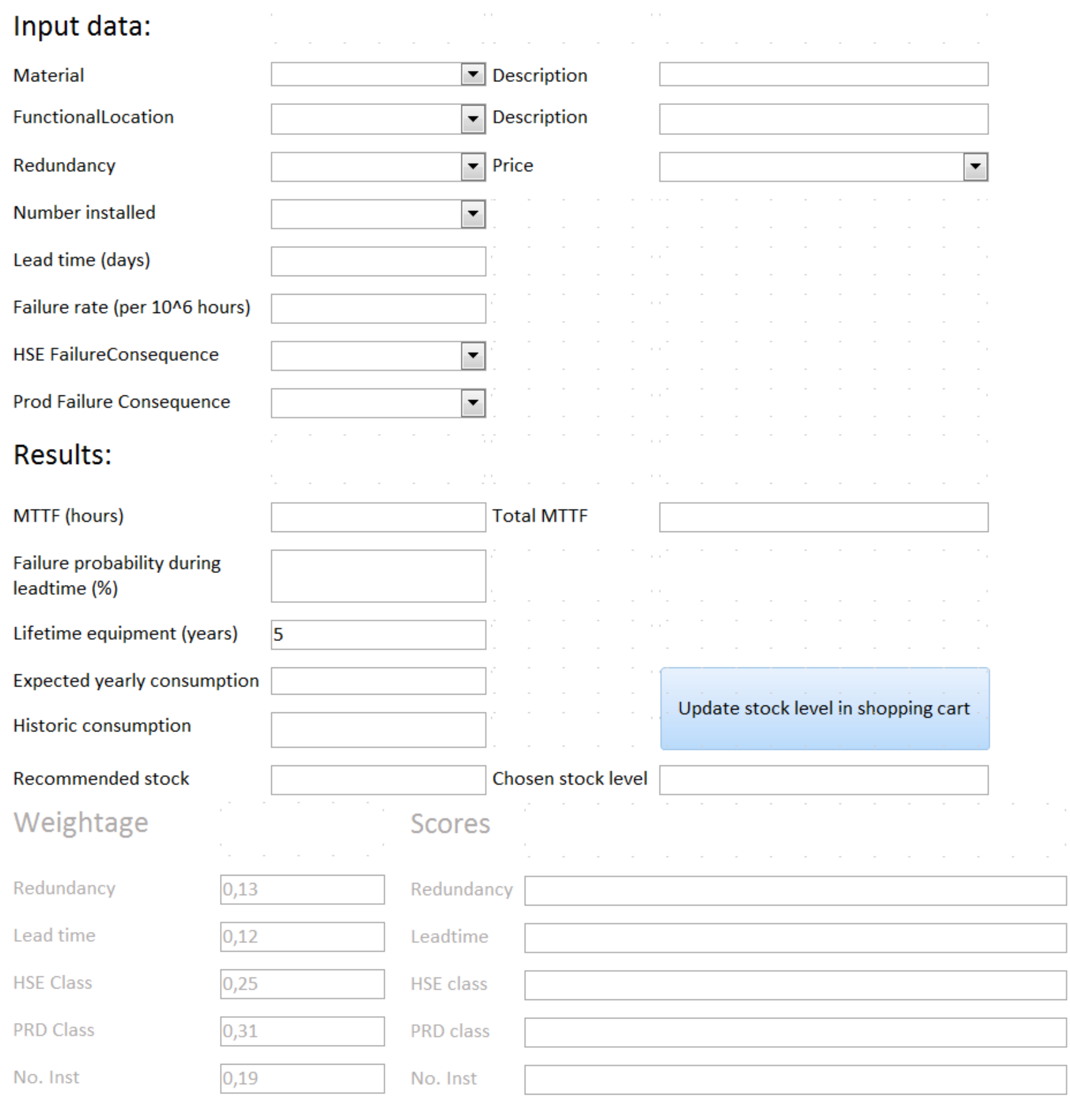


Figure 5-24 Layout view of frm_DecideSpareQuantity

When using this form, the user is able to choose material from a dropdown list. This list is the list of materials that have been added to the table “tbl_ShoppingCart”. When choosing material the form will automatically fill in data in description, failure rate, price, MTTF and historic consumption fields. Number of times installed, and lead time must be chosen from the associated dropdown lists. The user also need to choose functional location. All functional locations associated with the material are available from the dropdown lists. When the functional location is chosen, failure consequences, redundancy and description is updated. At that point all fields are filled out, and the form will display a recommended stock at the bottom. The recommended stock is calculated by the following formula.

$$Stock\ level = [\frac{HSE_S * HSE_W}{3} + \frac{Lead\ time_S * Lead\ time_W}{3} + \frac{PRD_S * PRD_W}{3} + \frac{Red_S * Red_W}{3} + \frac{NoInst_S * NoInst_W}{3}] * (Expected\ consumption)$$

Where subscript S and W, is score and weightage respectively.

If the result is <1, the form recommends stock level 1 because it is already decided to stock the material in form “frm_DecideSpareQuantity”. Next to the recommended stock field, there is a field for choosing stock level. The chosen stock level has to be entered manually, as there might be reasons for choosing lower or higher stock levels than recommended, for example that the material chosen is a special tool necessary for work on the equipment. When the user is satisfied with the chosen stock level, pressing the blue button updates the quantity in the table “tbl_ShoppingCart”.

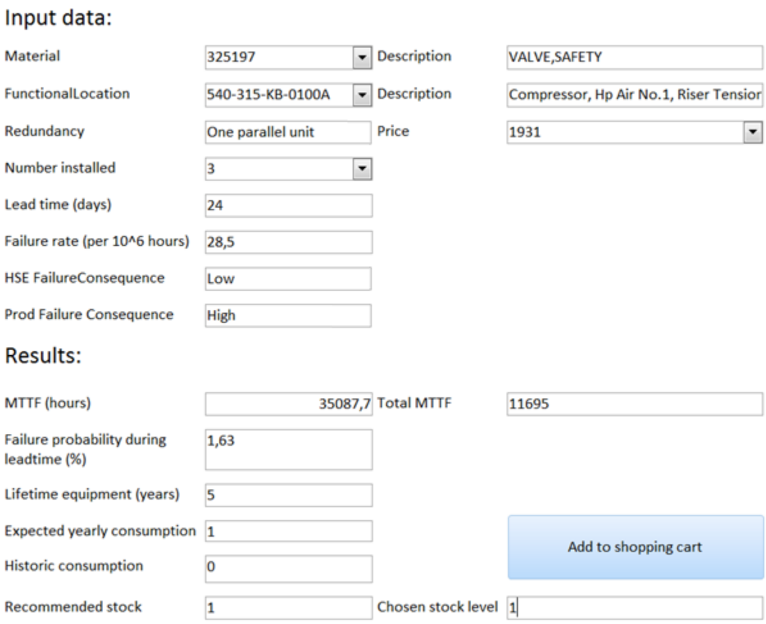


Figure 5-25 Filled out form

5.7.3.3 Frm_DecideSpareQuantityManual

This form is has the same function as form “frm_DecideSpareQuantity”. There are two major differences of the two forms. The first is that this form is connected to the “tbl_Material” table, instead of the “tbl_ShoppingCart” table. This lets the user choose any material in the database, not only those from “tbl_ShoppingCart”. The second is that most of the fields require manual input. The only automatically filled fields are description fields, historic consumption, MTTF, and recommended stock.

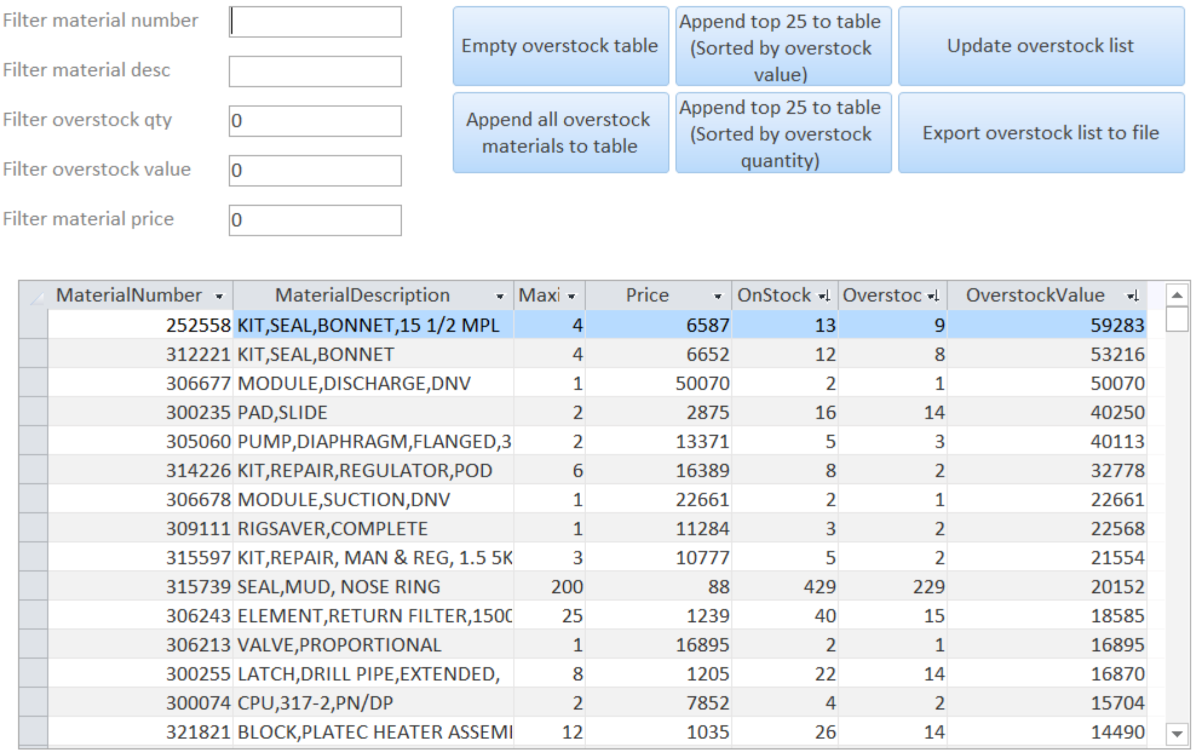
There are some pitfalls with this form. Not all materials are connected to functional locations. If the material chosen for analysis, is not connected to a functional location, the user will not get any “hits” when using the functional location dropdown list. The same issue is with number installed. When trying to choose number installed from the dropdown list and the material is not connected in any BOMs, the list will only show a blank field. Then the user has to enter the number manually.

The reason for creating this manual form is to give users a possibility of examining a specific material that certainly should be stocked, without having to use “frm_DecisionAid” first. The form can also be a check to see if the ROP or MSL settings are reasonable.

When using this form, the user also has the possibility of adding the material to “tbl_ShoppingCart”, in order to save their data.

5.7.3.4 Frm_Overstock and frm_Overstocksubform

The overstock form is used to see which materials are overstock. The criteria as overstock is that the on stock quantity is higher than the maximum stock level, which is set in SAP. As the current situation analysis showed us, 926 of 7959 materials with MRP type VB is overstocked. This adds up to an overstock value of $1.17 million. To create an overview of the overstocked materials, a form where the user can filter on different parameters was created. There are three filters, which allows the user to filter materials on overstock quantity, overstock value, and material price. After a filter is applied the user must use the “update overstock list” button for the filter to be activated. There are also filters for material number and description which updates the list continuously if the user decided to use these.



MaterialNumber	MaterialDescription	Maxi	Price	OnStock	Overstoc	OverstockValue
252558	KIT,SEAL,BONNET,15 1/2 MPL	4	6587	13	9	59283
312221	KIT,SEAL,BONNET	4	6652	12	8	53216
306677	MODULE,DISCHARGE,DNV	1	50070	2	1	50070
300235	PAD,SLIDE	2	2875	16	14	40250
305060	PUMP,DIAPHRAGM,FLANGED,3	2	13371	5	3	40113
314226	KIT,REPAIR,REGULATOR,POD	6	16389	8	2	32778
306678	MODULE,SUCTION,DNV	1	22661	2	1	22661
309111	RIGSAVER,COMPLETE	1	11284	3	2	22568
315597	KIT,REPAIR, MAN & REG, 1.5 5K	3	10777	5	2	21554
315739	SEAL,MUD, NOSE RING	200	88	429	229	20152
306243	ELEMENT,RETURN FILTER,150(	25	1239	40	15	18585
306213	VALVE,PROPORTIONAL	1	16895	2	1	16895
300255	LATCH,DRILL PIPE,EXTENDED,	8	1205	22	14	16870
300074	CPU,317-2,PN/DP	2	7852	4	2	15704
321821	BLOCK,PLATEC HEATER ASSEMI	12	1035	26	14	14490

Figure 5-26 Form view of "frm_Overstock"

The form is built up by two forms, the overall form “frm_Overstock” and the subform “frm_OverstockSubform”. The subform is the box displaying results in figure 5-26 and is created for the purpose of displaying the results from the query “qry_OverstockValue” as a datasheet in form view.

The form is linked with the table “tbl_OverstockList. This makes it easy to add materials from the list directly to the table for further manipulation, or directly export the overstock list to an Excel file. There are three buttons for appending overstock materials to the table, depending on if the user wants all materials, top 25 based on quantity, or top 25 based on overstock value added to the list. A button for updating the results within the form, based on the filters the user has chosen. A button for emptying the table, that way the user do not have to manually empty the table. And a button for exporting the entire list of overstock materials to an excel file.

5.7.4 Macros in Access

What are macros?

> *Macros are an automatic way for Access to carry out a series of actions for the database. Access gives you a selection of actions that are carried out in the order you enter. Macros can open forms; run queries, change values of a field, run other Macros, etc. the list is almost endless. (Simply-Access, 2015)*

Macros can be created either as SQL code, or in the macro builder. In the framework, macros has been used for smoother function of the forms. In the thesis not all macros are described, but the function of macros is explained through an example.

In the Access database macros are mostly used in the forms. Macros are added from the event tab on the property sheet. On the property sheet, the user can decide when the macro is run. In figure 5-27 the macro is added to the “After Update” field, and will run after the “InputM” field (highlighted in orange) is updated when using the form.

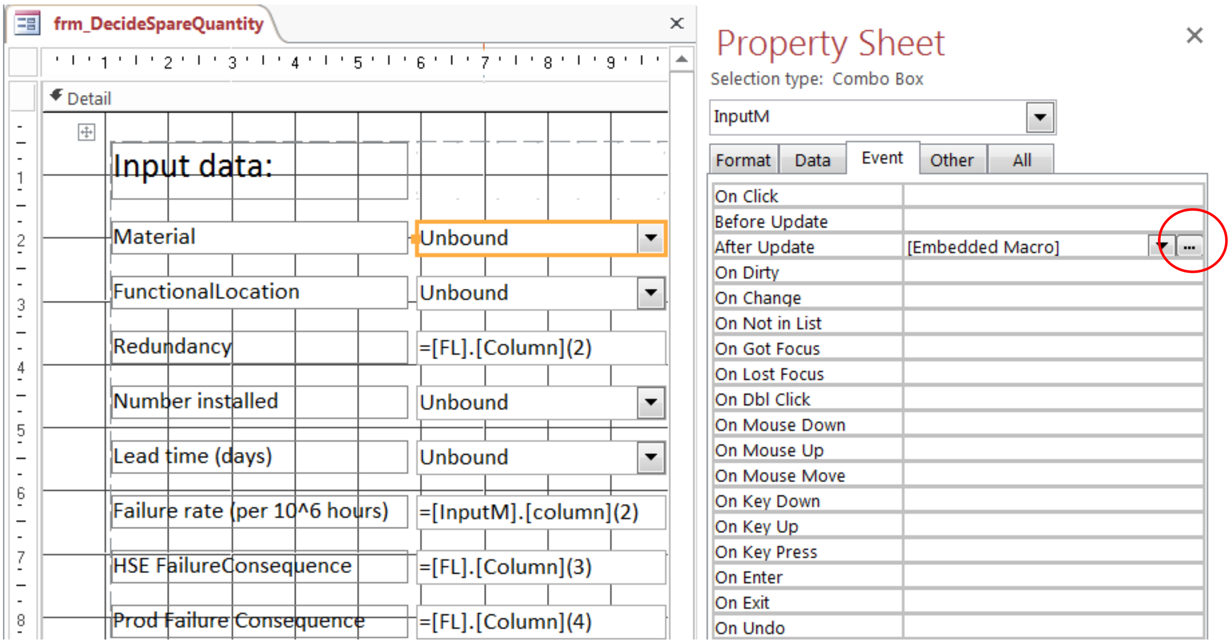


Figure 5-27 Macros are added from the property sheet by pressing the three circled dots.

The macro is shown in figure 5-28, the macro re-queries the control names FL, LeadT, and NoInst. This means that the fields, functional location, lead time and number installed, in the form are updated based on the material that is chosen when using the form "frm_DecideSpareQuantity".

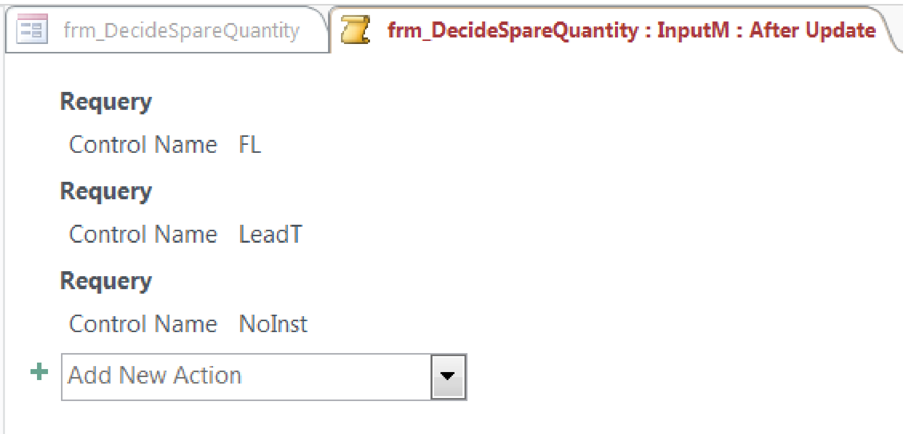


Figure 5-28 Macro from "frm_decideSpareQuantity"

5.8 Results of the framework

By implementing the proposed framework DD can improve their spare part strategy, as well as achieving a higher focus on reducing spare part inventories while minimizing the risk of HSE incidents or downtime. The spare part strategy should include deciding inventory levels by using the forms, "frm_DecisionAid" and "frm_DecideSpareQuantity". It is possible to use the form “frm_DecisionAid” to go through the entire BOM structured by choosing functional location. Materials from the BOM that are determined to be stocked are added to the table “tbl_ShoppingCart”, then the ROP is decided by using “frm_DecideSpareQuantity”.

In the current situation analysis, it was discovered that many materials are not connected to functional locations or equipment by BOMs. Because of this a form for deciding stock levels for such these materials was developed. This is based on the same parameters as “frm_DecideSpareQuantity”, but requires information such as failure rate, consequence classification, number installed, etc. to be entered manually.

The use of forms makes it possible to justify and document the spare part needs, by displaying the relevant parameters, and showing what potential costs of not having sufficient spare parts on stock are. This makes it easier for the finance people to understand what impact reducing spare part inventories to a minimum will have. Even though not all functional failures lead to downtime, there are other related costs to failure, such as reduced capabilities of a pumping system, or further damage leading to a bigger repair if it is not done within a short time period.

Overstocked materials are easy to find with the framework, and overstock form. When reporting overstock this should lead to a count of the physical inventory, raise the ROP and/or MSL, or impose a procurement stop on the overstocked materials.

6 Examples showing framework results

In order to show how well the framework of determining spare part stock levels work, it was used to determine spare part stock levels for a selection of equipment; six functional locations, including three types of smoke and gas detectors, and 20 of 50 most overstocked materials. By using the framework for a variety of materials it has been tested for functional locations with different consequence classifications and value of spare part lists.

The chosen functional locations have different consequence classifications, number of spare parts and serve different functions. Table 6-1 show the equipment that was analyzed with the framework to decide spare part stock levels. The table shows consequence classification, number installed and necessary operative units, and number of spare parts in BOM. The smoke/gas detectors does not have a BOM as they are replaced like for like at failure, or at a predefined maintenance interval, whichever comes first.

Functional location description	Redundancy	Functional failure consequence			Number installed	Operative units	Spare parts in BOM
		HSE	Prod	Cost			
Valve, gate, C&K manifold, no 1.	No redundancy	High	Low	High	21	21	15
Compressor, service air no 4	One parallel unit	High	High	Low	4	2	15
Pump, No 1 HP Mud	Two or more parallel units	High	High	Low	5	3	86
Hydrocarbon gas detector	No redundancy	High	Low	Low	52	52	0
H2S Gas detector	No redundancy	High	Low	Low	4	4	0
Smoke detector	No redundancy	High	Low	Low	522	522	0

Table 6-1 A selection of equipment used to show the results of the framework.

The focus in this thesis is to optimize number of spare parts in stock by keeping as low spare part inventory value as possible, without risking downtime or HSE due to savings in the spare part inventory. When spare part stock levels was determined, all functional locations the spare part can be used was considered. That means that the spare part list does not need to be stocked per valve, or compressor, but by following the recommended stock levels spare part needs for all redundant or functional locations with the same BOM are covered.

When utilizing the framework a day rate of $ 240 000 was used. The lead time attribute are not updated for all materials, therefore SAP transaction ME2M was used to find lead times from historic purchase orders.

6.1 Choke and kill manifold, valve 1.

The first category chosen for demonstration of the decision framework is valve number 1 in the choke and kill manifold, 540-336V0001. The manifold is used for well control, by controlling the back flow from the well (choke), or providing pressure to the well to stop the back flow (kill). In total there are 35 valves that can be opened and closed separately. The sizes of the valves are; 2 1/16", 3 1/16", or 4 1/16". 21 of them are 3 1/16" that is why this size was chosen. According to NORSOK and Performance standards (PS10), the entire manifold has to be certified every 5th year because it is a well barrier.

The failure consequence classification of the functional locations shows high HSE failure consequences, low production failure consequences and no redundancy.

In table 6-2, the recommended stock levels for spare parts to the valve is shown next to today's stock levels. The total value of the recommended stock levels are $ 144735, and value of the current stock level is $ 132598. That is a difference of $ 12137 or 9.2 % higher than current on stock value. The difference is mainly because of two materials, the seal assembly and cushion fluid flange. These two materials counted for $ 12028 of the total difference.

Material	Material Description	Recommended Stock level	Rec stock value ($)	Reorder Point	On Stock	On stock Value ($)	Maximum Stock Level
301821	VALVE,GATE,MAGNUM,15K,3 1/16"	4	99208	0	4	99208	0
301822	SEAL	4	32	4	12	96	8
301823	BEARING,THRUST	5	250	4	14	700	8
301824	RING,SEAL	5	25	2	6	30	4
301825	PACKING,ASSEMBLY	4	1720	2	5	2150	4
301826	GASKET,BONNET	5	2150	3	4	1720	6
301827	GATE	4	11416	2	3	8562	4
301828	RING,SEAL	6	42	2	6	42	4
301829	PLUG,BLEEDER	9	378	2	18	756	4
301830	SEAL	6	24	5	12	48	10
301831	SEAL,ASSEMBLY	4	15944	2	2	7972	4
301852	FLANGE,CUSHION,FLUID,3 1/16",15K	4	8112	0	2	4056	0
301854	FLANGE,ASSY,CROSSOVER,9 1/16" AOUTCLAVE	1	1488	0	1	1488	0
301855	GAUGE,PRESSURE	1	3490	1	1	3490	2
301856	GASKET,RING,BX154,316	6	456	1	30	2280	2
		Total:	144735		Total:	132598	

Table 6-2 Recommended spare parts for the kill and choke valve

6.2 Air compressor

The BOM connected to compressor, service air no 4, 540-733-KC-0104 is analyzed in this section.

Bolette Dolphin has four service air compressors. It is necessary that 2 of 4 is running at all times. Without the service air compressors much equipment that is dependent on compressed air cannot run. That has resulted in a failure consequence classification with score high on both production and HSE and one parallel unit. From OREDA the failure rate is of 84.56 failures per million hours (calendar time). This was used as input in the framework for recommending stock levels. Table 6-3 compares the recommended stock level against today’s stock levels. The result is that the total value of the spare parts the framework recommends is $ 34930 lower than the value of the current spare part inventory, equivalent to a saving of 46%.

Material	Material Description	Recommended stock level	Rec Stock value ($)	Reorder Point	On Stock	On stock value ($)	Maximum Stock Level
311654	FILTER,SERVICE,KIT,FOR,TMC105235	2	3768	0	7	13188	0
309168	VALVE,SOLENOID	2	826	2	3	1239	4
311655	KIT,SEPERATOR,TMC105235 AIR COMPRESSOR	3	6150	4	6	12300	8
311656	SEAL,KIT,FOR,DISCHARGE,VALVE	2	1784	4	4	3568	8
311657	MAINTENANCE,KIT,FOR,TMC105235	2	9936	2	5	24840	4
311658	OIL,CHANGE,KIT	2	1086	6	11	5973	12
311659	SEAL,SHAFT,KIT,FOR,TMC105235	2	1556	2	4	3112	4
311662	CYLINDER,LOADING	2	3526	1	1	1763	2
311663	SEAL,KIT,FOR,LOADING,CYLINDER	2	1176	2	2	1176	4
311664	SPRING	4	304	1	1	76	2
311665	RING,COUPLING,ELASTIC	2	6940	1	1	3470	2
329977	NUT,WING	4	4	0	6	6	0
329979	ELEMENT,FILTER,AIR	3	1629	4	5	2715	8
335528	DRAIN,CONDENSATE,ITEM 1	2	1276	1	2	1276	4
340445	VALVE,BLOWDOWN	3	567	3	4	756	6
		Total:	40528		Total:	75458	

Table 6-3 Recommended spare parts for the air compressor

6.3 Smoke and gas detectors

Stock levels of smoke and gas detectors was analyzed using the framework. Detectors do not have any spare parts but are replaced one to one at failure or at the predefined maintenance interval. It is therefore important to have spare detectors available. When they fail, they are either sent onshore for repair, or scrapped. The three types analyzed are:

- SENSOR,MULTI,OPTICAL,HEAT, SMOKE DETECTOR (305008)
- DETECTOR,GAS,HYDROCARBON,INFRARED POINT (130733)
- DETECTOR,GAS,H2S,0.50PPM,STAINLESS STEEL (305014)

Material	Number installed	Failure rate	ROP (MSL)	On stock	Recommended stock level	Probability of failure during lead time
305008	522	3.40	10 (20)	7	12	0.49 %
130733	52	7.79	0 (0)	0	3	1.12 %
305014	4	11.46	1 (2)	2	1	1.64 %

Table 6-4 Smoke and gas detectors

The recommended stock level corresponds quite well with the ROPs that are in SAP, except for the hydrocarbon gas detector, which does not have a ROP or MSL. It is cause for concern when there are no available hydrocarbon gas detectors. The reason for why there are no available detectors is unknown. In this category costs has not been focused on, as smoke and gas detectors are important to have available as this is a safety matter.

6.4 Overstock

To take a closer look at the overstock list, the 20 of the top 50 overstocked materials was analyzed using the framework. The results are shown in the table below. Total values of recommended stock levels, current reorder point and current stock level values are also shown in comparison. It is easy to see from this table that the reason that they are overstocked is due to not following the set maximum stock level. The current reorder points are set at reasonable levels according to expected consumption and other important parameters discussed in section 5.3. Compared to the recommended stock levels from the framework, the savings is $ 22669, or 12.8%.

Material	Material Description	Rec. stock level	Rec. Stock value	ROP	ROP Value	On stock	MSL	On Stock Value
34055	KIT,SEAL,VALVE,F/AF114,1/2"SPM,3WNC	1	310	5	1550	39	10	12090
34174	KIT, SEAL, FOR AG261 1" SPM BI-DIR	1	237	1	237	24	2	5688
56846	BAFFLE,INTERMEDIATE ROD	4	300	4	300	42	6	3150
300325	CARD,CONTROLLER	2	1468	1	734	16	8	11744
301651	CABLE,AROURED,SHEATH,XT125,08X02X16	3	216	100	7200	255	200	18360
306213	VALVE,PROPORTIONAL	1	16895	1	16895	2	1	33790
306243	ELEMENT,RETURN FILTER,1500L,ANTI STATIC	4	4956	15	18585	40	25	49560
308790	VALVE,SPRING	1	450	1	450	27	3	12150
314224	SEAL,PACKER,RETAINER,1/2"	2	126	15	945	74	30	4662
341343	UNIT,COMPLETE,HEAT EXCHANGER PLATE	1	14454	1	14454	2	1	28908
306677	MODULE,DISCHARGE,DNV	1	50070	1	50070	2	1	100140
306678	MODULE,SUCTION,DNV	1	22661	1	22661	2	1	45322
309111	RIGSAVER,COMPLETE	1	11284	1	11284	3	1	33852
300074	CPU,317-2,PN/DP	1	7852	1	7852	4	2	31408
301032	EXTENDER,KVM-FIBER	1	6816	1	6816	4	2	27264
300235	PAD,SLIDE	1	2875	1	2875	16	2	46000
102208	MODULE,OUTPUT,ANALOG,8 CH	2	4068	1	2034	9	4	18306
300255	LATCH,DRILL PIPE,EXTENDED,	6	7230	4	4820	22	8	26510
321821	BLOCK,PLATEC HEATER ASSEMBLY,68KW	1	1035	6	6210	26	12	26910
327531	CLAMP,FULL ASSY (6.5" C&K OD)	1	1035	1	1035	10	2	10350
		Total:	154338	Total:	177007		Total:	546164

Table 6-5 Recommended spare part stock levels, for materials currently overstocked

6.5 Mud pump

Mud pumps are often described as the heart of drilling operations. Without it mud, drilling will quickly come to a halt. On Bolette Dolphin there are 5 mud pumps, functional locations 540-325-BK-0100A-E. As they are that important for the drilling operation they have been classified with high failure consequences of both HSE and production. For most operations it is necessary with at least 2-3 operational pumps, making the mud pump system redundant with 2 parallel units.

OREDA provides a mean failure rate of 6.9 failures per million hours for a reciprocating pump. This failure rate has been used for most materials, as most of the spare parts are not listed in OREDA. Where failure rates are available for specific materials, this was used.

The current spare part inventory for the mud pumps are valued at $314796, and value of inventory following the current ROPs are $175893. The overstock value of the mud pumps' spare part inventory is $124295. The result of the decision framework is recommended stock value of $165822, corresponding to savings of 5.7%.

Material	Material Description	Price	Rec stock level	Rec St value ($)	ROP	ROP value ($)	On Stock	On stock Value ($)	MSL
56823	HOLDER,GUIDE,VALVE,FLUID END	23	1	23	3	69	18	414	6
56824	INSERT,GUIDE,VALVE,FLUID END	16	1	16	6	96	36	576	12
56846	BAFFLE,INTERMEDIATE ROD	75	1	75	4	300	42	3150	6
56862	GASKET,LINER,RUBBER,6",FLUID END	26	1	26	0	0	0	0	0
56863	GASKET,LINER,RUBBER,7",FLUID END	50	1	50	0	0	0	0	0
56865	GASKET,CLEAN OUT,POWER END	111	1	111	2	222	6	666	4
56888	NUT,PISTON,1 1/2"-8 ELASTIC STOP	25	1	25	9	225	18	450	18
56898	PISTON,SUPREME,7",FLUID END	180	1	180	0	0	0	0	0
85418	CONDUCTOR,OIL,POWER END	28	1	28	2	56	3	84	3
85452	GASKET,LINER,RUBBER,6.1/2",FLUID END	16	1	16	20	320	40	640	40
85455	GASKET,COVER,WRENCH,POWER END	14	1	14	2	28	0	0	3
85510	PLUG,MAGNETIC,1",POWER END	20	1	20	2	40	4	80	4
232295	SEAL,MODULE,SUCTION,FLUID END	20	1	20	6	120	6	120	8
232301	O-RING,FLUID END	18	1	18	4	72	4	72	8
232340	GASKET,RTJ,BX-169,FLUID END	18	1	18	4	72	12	216	8
240179	GASKLET,LINER,RUBBER,5.1/2",FLUID END	21	1	21	0	0	16	336	0
243883	LINER,SUPREME,5.1/2",FLUID END	629	1	629	0	0	31	19499	0
245066	RING,BACK-UP,FLUID END	54	1	54	2	108	1	54	4
245321	SET,GASKET,COVER,POWER END	149	1	149	2	298	2	298	4
246249	STRAINER,DISCHARGE,FLUID END	1574	1	1574	1	1574	2	3148	1
247412	SEAL,OIL,SHAFT,PINION,POWER END	614	1	614	2	1228	4	2456	4

251186	GASKET,RETAINER,WIPER,POWER END	17	1	17	3	51	0	0	6
251187	GASKET,PLATE,RETAINER,POWER END	32	1	32	3	96	3	96	6
251189	GASKET,PLATE,GAUGE,OIL,POWER END	106	1	106	2	212	4	424	4
251190	GASKET,BEARING,MAIN,END CAP,POWER END	45	1	45	2	90	4	180	4
251192	GASKET,BEARING,PINION,POWER END	91	1	91	2	182	2	182	4
251194	WIPER,ROD,INTMD,POWER END	91	1	91	3	273	6	546	6
251195	ROD,INTDM,BLAK JAK	4393	1	4393	1	4393	1	4393	1
251196	LINER,CROSSHEAD,POWER END	5863	1	5863	1	5863	1	5863	1
251197	SHIM,LINER,CROSSHEAD,0.005",POWER END	34	1	34	10	340	15	510	15
251208	CONNECTOR,DISCHARGE,FLUID END	1576	1	1576	1	1576	2	3152	2
251209	ADAPTER,DISCH CONNECTOR,PUMP,COMPLETE	474	1	474	1	474	2	948	2
251210	ROD,PISTON,PUMP,COMPLETE	246	1	246	1	246	12	2952	3
251211	SUB-ROD,PUMP,COMPLETE	45	1	45	1	45	18	810	3
251212	CLAMP,ROD,PUMP,COMPLETE	159	1	159	3	477	21	3339	6
251214	PLATE,WEAR,FLUID END	494	1	494	2	988	8	3952	4
251219	SEAL,MAINIFOLD,SUCTION,FLUID END	31	1	31	1	31	3	93	3
251220	PACKING,VALVE COVER,FLUID END	32	1	32	16	512	36	1152	36
251221	GUARD,SPLASH,PUMP,COMPLETE	170	1	170	3	510	3	510	6
251222	HOSE,FLUSH,LINER,FLUID END	49	1	49	6	294	0	0	9
251223	O-RING,FLUID END	23	1	23	2	46	2	46	4
251225	SEAL,SPACER,DISCHARGE,FLUID END	25	1	25	2	50	2	50	4

306659	SPRING,VALVE,FLUID END	14	1	14	32	448	72	1008	68
306661	PUMP,CENTRIF,FLUSH,LINER	1050	1	1050	1	1050	3	3150	3
306670	VALVE,COMPL,FLUID END	157	25	3925	36	5652	50	7850	72
306671	SEAT,VALVE,FLUID END	179	25	4475	36	6444	54	9666	52
306673	LINER,ZIRCONIA,6 1/2"	3694	4	14776	4	14776	4	14776	8
306674	PISTON,BLUE LIGHTNING,COMPLETE,6 1/2"	561	12	6732	15	8415	36	20196	25
306675	VALVE,SUCTION,GUIDE	492	1	492	1	492	1	492	2
306676	VALVE,DISCHARGE,GUIDE	492	1	492	1	492	1	492	2
306677	MODULE,DISCHARGE,DNV	50070	1	50070	1	50070	2	100140	1
306678	MODULE,SUCTION,DNV	22661	1	22661	1	22661	2	45322	1
306679	MANIFOLD,DISCHARGE	17958	1	17958	1	17958	1	17958	0
306680	MANIFOLD,SUCTION	18732	1	18732	1	18732	1	18732	0
306681	HOSE	19	1	19	2	38	4	76	4
306682	SHIM	104	1	104	2	208	2	208	4
306683	GAUGE,PRESSURE,0-200PSI/KPA,2 1/2"DIAL	91	1	91	2	182	1	91	4
306684	GAUGE	71	1	71	2	142	0	0	4
306685	SHIM	9	1	9	2	18	10	90	4
321865	VALVE,2-1/16",7.5K,MODEL200M,MUD,VALVE	6298	1	6298	1	6298	2	12596	0
333433	SEAL,VALVE COVER FLUID END SOUTHWEST	8	22	176	30	240	62	496	60
			Total:	165822	Total:	175893	Total:	314796	

Table 6-6 Recommended spare parts for mud pump

6.6 Summary of examples

The example shows that the decision framework described in this thesis that DD may save up to 46% on spare part inventories. The savings was respectively 46%, 12.8%, and 5.7% for air compressor, overstock materials, mud pump spare parts. For the choke and kill manifold valve, the result was a recommended spare part inventory 9.2% higher than the current inventory value. On average the savings is approximately 13%. If the entire spare part stock is reduced by 10%, this adds up to approximately $1.8 million, only for Bolette. This is without analyzing capital spares, as they are not depreciated in the individual MODUs budget. DD currently have 10 MODUs in their fleet. If the spare part inventory in the entire fleet is reduced with 10% the savings adds up to a substantial sum, which proves the potential for implementing this framework.

The parameters that influence the results of the framework most are number installed and failure rates. If a material is installed 15 places and have a failure rate of 40 failures per million hours, it is reasonable that more spare parts are stocked for that material than a material that is installed one place with the same or lower failure rate.

Reducing the total spare part inventory will reduce the capital tied up in parts, making it available for other purposes. Reducing inventories will in turn reduce work load for keeping spare parts in good condition, as well as reduce the need for storage space. The framework does not always provide the best recommended stock levels, but it is a good indication and by using the framework together with experience and understanding of the expected consumption provide reasonable levels of spare parts.

The framework has shown that stock levels regarding smoke and gas detectors are low. Especially for hydrocarbon gas detectors which there are 52 installed, and no spare detectors.

When using the framework it is advantageous to have lead time of materials available. As mentioned, all materials have a lead time of 70 days in SAP. Therefore those lead times were disregarded, and historic lead times were used instead. If DD not implements lead time in SAP for each material, the framework takes longer time to use, as old purchase orders has to be looked up in SAP or lead times must be provided by the supplier. The implementation of lead time for materials can be done in the same manner as prices, namely by having an average lead time which is automatically updated each time the material is purchased.

7 Results and discussion

7.1 Framework

The thesis proposes two forms that maintenance personnel can use to determine spare parts stock levels. It was shown that by using the forms for deciding stock levels, DD can reduce their spare part inventory, and save money. It must be mentioned that the framework must be used alongside some experience and knowledge concerning rules and regulations, as well as common sense. A simulation to verify that the recommended stock levels will be sufficient to keep the MODU in operation without any major stops due to lack of spare parts, has not been performed. Assuming failure rates provided by OREDA are trustworthy, the framework provides a reasonable and sufficient spare part inventory. The thesis has proposed a framework for spare part management that easily can be established across the organization, the framework can also be used to justify the spare part inventory.

Maintenance will always be a support function of the main business process of the offshore drilling industry, and in order to increase profit all processes are under consideration when trying to cut expenses. The disadvantage of cutting expenses in the maintenance department is that the future expenses of equipment increases as they get shorter useful life due to poor maintenance. By cutting the maintenance budget a result may be more failures leading to more corrective maintenance and downtime. When deciding spare part stock levels there are mainly three departments that want to influence the stock levels. It is the financial department, the operational department and the maintenance department. Especially because the financial department want to cut costs of maintenance by reducing spare part levels, it is important to be able to justify the spare part stock levels.

The framework of deciding spare part stock levels can be divided into a 3 step process.

1. Using the form “frm_DecisionAid” to map all costs, and decide if the spare part is necessary to keep in stock
2. Using the form “frm_DecideSpareQuantity” to get a calculated recommended stock level.
3. Evaluate if the recommended stock level is appropriate, and update recommended stock levels. The form does not recognize the material description, in some BOMs materials that are used for testing, or special tools, are included. For such materials it is often sufficient with one on stock.

There are both pros and cons of the framework, the most important are listed below.

Pros:

- Matches well with reality
- Saves money by reducing stock levels
- Makes decision maker aware of relevant parameters
- Easy to see what is overstocked
- Possible to override the recommended stock level
- Easy user interface

Cons:

- Requires manual input of failure rates
- Some intuition has to be used
- Easier to use if BOM is already established
- Not possible to run through all BOMs automatically
- Not simulated over a long period to see that it does not affect downtime

If the framework had provided results far off current stock levels, it would have pointed in the direction that it was unreliable because ROPs and MSLs has been set according to experience and rule of thumb. As seen from chapter 6, the recommended stock levels are generally at similar but slightly lower than current ROPs. This is a sign that the framework is reliable.

The framework cannot always be used blindly. Some equipment spare part stock levels must be according to rules and regulations. The framework does not account for any regulations, and it is required that the user is aware of the relevant regulations. In addition, some materials in BOMs are not necessary to have more than one of, if a high failure rate is entered for these materials, the recommended stock of these materials will be higher than necessary. In those cases the users should see that, and only choose to stock one.

By using the framework for determining stock levels, the user becomes aware of all parameters that may influence spare part stock levels. When aware of the parameters a better decision can be made, than if the decision is based on rule of thumb.

When making the first decision, if the spare part should be stocked or not, it is necessary that the spare parts are connected to BOMs of equipment of functional locations. Then the BOM can be used in form “frm_DecisionAid”, and each material can easily be evaluated. Without the BOM, that task has to be done manually.

The overstock form gives the user a clear picture of materials that are stocked higher than maximum stock levels. It is easy to create an overstock report that can be used to increase focus on not stocking more than necessary. As there are many possible reasons for stock inventories are overstocked, the overstock list provides a good incentive to double check the physical spare part inventory to find out if the data are correct.

7.2 Results from the current situation analysis

While working with the thesis several findings related to DDs spare part management were made. These findings provide improvement potential in spare part and maintenance management. The findings will first be listed and then discussed in separate sections.

- Incomplete material information
  - Duplicate materials
- Tracking number of repairs to serialized materials
- Overstocking.
- Materials not connected to functional locations

7.2.1 Incomplete material information

When using the MM03 transaction in SAP it is possible to look at all the attributes of materials. Not all of them are used by DD. It takes time to fill out the information for each material that is created, and that not all attributes will give additional value to the user. But some of the possible fields should be filled out. The most important attributes that either does not have any information, or wrong information is lead time, price, weight and volume. These attributes can make material planning easier for the maintenance crew, even though the information is not 100% correct. For example knowing that the lead time from supplier to the base is usually 15-30 days instead of not knowing anything, is valuable in the planning phase of corrective maintenance.

674 spare parts in BOMs have a price of $0. As mentioned, prices in SAP are not updated until the material is purchased. But most of these materials have been purchased, and should have price. By having prices of all materials that are stocked, it would be possible to get the real value of the spare part inventory. That is not possible today. Usually when a material number is created, it is when a MODU needs that specific material. Then the person creating

the material will have a price and lead time at hand, even though this might not be 100% correct, it is close to the real value.

There are many duplicate materials, from a quick analysis it was found that 582 manufacturer's part numbers are used for two or more materials. When creating new materials for purchase, it should be put in more effort to find out if the material is already created in SAP. This way DD will avoid having material lists containing more materials than physically on the rig.

7.2.2 Number of repairs are not tracked

A typical equipment sent to vendor for repair are electric motors. DD policy is to repair materials if the repair cost is less than 60%. Repaired equipment is not always as good as new equipment, and after some repairs the failure rate of the motor will be higher than a new motor. By tracking the number of repairs of serialized materials, DD would be in a better position to decide to replace the motor with a new, rather than repairing it for 50-60% of the new price. SAP already has processes addressing this issue, but DD does not use them.

7.2.3 Overstocking

From the current situation analysis, chapter 4, it was shown that DD has overstocked materials for a total value of $ 1.17 million, or 6.5% of the total measurable inventory value. Overstock materials is defined as materials with higher stock levels than the defined maximum stock level. The maximum stock level is defined for all materials with MRP type VB.

There may be several reasons for overstocking. One is that the actual on hand quantity is not correct in SAP, because the storekeeper has not updated the stock levels. Another cause is that all of the parts purchased for the five yearly rig classification was not used, and transferred to the spare part stock. A third cause is that the maintenance personnel thinks the maximum stock levels are too low, and ordered more spare parts to avoid getting in the situation of not having the necessary parts. If so they should also have communicated with the onshore maintenance team to increase the levels if necessary. It should also be picked up by the procurement department that materials are ordered even though the stock levels are above, or close to the maximum stock level. Most likely it is a combination of these and maybe other reasons that Bolette Dolphin has large overstock values. The only thing to do about it is to create overstock reports, this way it could be further checked out, and if necessary stop procurement of materials with stock levels above or equal to the maximum stock level. Eventually ROP and MSL may be changed.

7.2.4 Spare parts not in technical hierarchy

Many spare parts are not attached to a BOM, equipment or functional locations. This makes it hard to find out where the material is connected. By using the SAP transactions CS15 (figure 7-1) or CS06 (Display Material BOM group) more or less all materials should be connected to either a material BOM, equipment BOM or functional location BOM. Many of the materials in SAP are difficult to trace back to a functional location because they are not BOMheaders, nor BOMdetail materials. That can mean several things, either that the material is not used at all, that it is used at a different MODU, or that the BOMs, are not complete. The list of unassigned materials comprises approximately 7000 spare parts, typical materials are bearings, seals, filters, etc. Consumables are not included in the list. This means that there are 7000 spare parts which require that the maintenance crew know where they belong, and where they can be used. If the crew do not know where the spare parts belong, it will be left in the storage indefinitely. This may in turn lead to a financial loss for DD, as spare parts that are purchased, stored for some years and scrapped because it was not needed, or is degraded. When all spare parts belong to a BOM, the list of duplicate spare parts will also decrease, as fewer material numbers will be created. This is because it becomes easier to find the spare part the technician is looking for, it also reduces time spent on the computer, creating more time for maintenance activities.

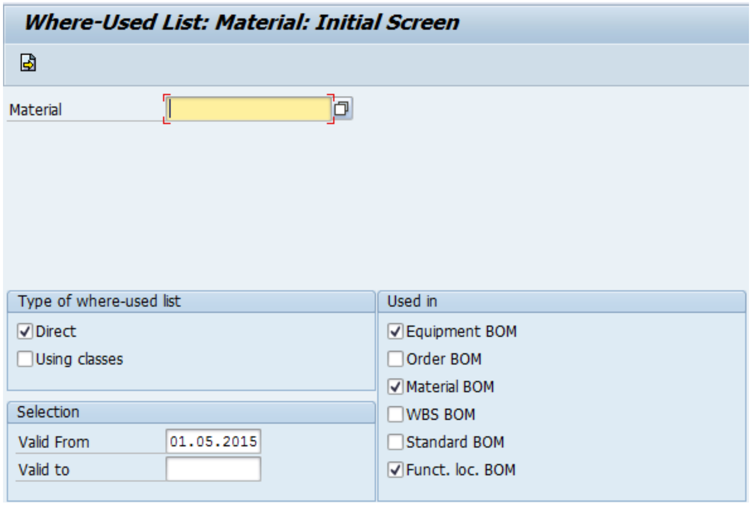


Figure 7-1 CS15 SAP transaction. Here the user can search for where materials is used by typing the material number.

7.3 Consequences of not having spare available

The consequences of not having spare parts available may be severe. This is why the spare part inventories often are higher than necessary, leading to capital being tied up in parts. The consequences of not having spare parts ranges from stopping the operation of the rig to nothing. This thesis addressed these consequences by using failure consequence classification of functional locations, as well as having a check box, that can be checked if materials may lead to downtime if they should fail. The reason is that it is not always easy to know which parts are most critical based on the failure consequence classification as it ranges from low to high. The consequence classification does not say anything about the individual materials, which is why it is helpful to include such a checkbox in the framework. Some equipment failures causes a stop in operation. Then the equipment must be repaired before commencing operation, if spare parts are not available an order for the necessary parts must be made. Sometimes other MODUs have the necessary part on hand, then the company operating that MODU are often helpful by selling the part directly to the company on downtime. The other option is to order the part as a downtime order.

Downtime orders are well known in the industry and the major equipment suppliers have systems to support rigs that suffer downtime due to equipment failure. Typical extra services that are available if rigs are on downtime is faster delivery on spare parts, available service technicians or other help to restore equipment function. These services often cost a lot, and typical downtime order premiums is a 100% markup fee in addition to the price. The alternative cost of having to shut down the rig while waiting is much higher, and this option will then be used. That means that there are more or less always a solution to restore functions if failure occur and spare parts are not available.

7.4 Equations/parameters

The main focus while developing the presented framework was to make an optimization which is understandable and practically possible to implement. Because of this focus complex equations requiring much manual input was kept to a minimum. This resulted in a spare part inventory framework based on parameters that are mainly static. Such as failure consequence classification of functional locations is initially static, but can change. If they change it is easy to update the tables containing the values that have been changed. By using live data, or exported data at predefined intervals, this is issue is solved.

The most unreliable parameter that are used in the framework is the failure rate. The reason for the unreliability of this parameter is that it has to be collected either from SAP, OREDA or OEM. Failure rates from SAP is scarce as Bolette Dolphin has only been in operation for approximately one year, for other MODUs the failure rates might be more reliable. OREDA data are collected from many installations and categorized by type of equipment. Regarding failure rates for a specific pump for instance NOV- 14-P-220 Mud Pump, cannot be obtained, as OREDA divide pumps as centrifugal, reciprocating and rotary. This means that when using OREDA data, the user has to find the most suiting equipment type.

The assumption of exponentially distributed failure rates means that failures in the “burn-in” phase is assumed to be non-existent. This assumption holds if all problems due to poor production quality are avoided. When installing new equipment there are strict procedures for commissioning and testing. This will sort out any issues during installation, which can lead to a higher failure rate than expected. When describing the failure process service levels was briefly explained. Service levels could have been implemented to further improve the framework for deciding spare part stock levels, but it was decided not to implement it. This is because there are not defined specific service levels per functional location, and it would introduce one more parameter that needs to be defined and entered. In the future by introducing service levels, this could be a part of the RCM analysis for functional locations, by doing that the RCM would be more complete as spare part stock levels could have been decided as a part of the RCM analysis.

When determining spare part stock levels, a parameter called total score is multiplied with the expected consumption. The total score is found by multiplying the weightage of each parameter (HSE/Production consequence classification, no. installed, redundancy, and lead time), with the scores of each parameter. The total score defines if the spare part should be considered vital (0,667-1), essential (0,334-0,666) or desirable (0-0,333). By using this scoring system DD achieve higher probability of having the most important spare parts available when needed. This is reasonable way of reducing stock levels, without negatively influencing uptime of the rig.

7.5 How to implement the framework

A framework has no value if it is not used, which is why it is important to have a plan for implementing the framework. There are several possibilities for the implementation. One is to use the Access database as is, and export data from SAP at predefined frequencies as input to the database. It is possible to set up Winshuttle to export defined datasets at set frequencies. It requires a bit more effort to set up Winshuttle than using the SE16N transaction, but if the data export from SAP will be done regularly it saves time as exporting data via SAP transactions has to be done manually each time. When setting up the data export it is important to set up the excel sheets with the same design as the tables in Access, to make the import to Access easier. Then DD can use Access directly to determine spare part stock levels and look up overstock materials.

Another possibility of implementing the framework is to use the Access database as a template and set up the same queries and calculations in a web-based system called QlikView. DD has already established a material management system in QlikView, making it the most likely option of implementation. QlikView updates inventory data automatically every morning. If DD decides to use QlikView, a separate page can be created by using the Access forms as templates. It requires some extra programming to develop the pages, but the data export does not have to be set up as it is already in place. Another advantage of adding it to QlikView is that all material management software will be in one place.

Failure rates from a MODU becomes more reliable as it is in operation. By using live data from SAP, DD can further take advantage of failure rates from the MODU instead of looking up failure rates in OREDA. This requires some editing of the tables, such as including number of failures, and repair times in the data export.

7.6 Data quality

For all optimization models it is important with reliable data. Most of the data, regarding materials and DD maintenance history, used for developing the framework was exported from SAP. Failure rates is a combination of fault reports in SAP and data from OREDA. Data from OREDA is compiled from maintenance systems from many different installations with different operating conditions. There are some uncertainties of the data collected in OREDA. Some of the factors that influence the data are:

- Different operating conditions
- Training and competence of crew
- Different maintenance strategies
- Computer literacy, poor data skills may influence the data entered

These factors affects the data that is collected, as some of it might be incorrectly entered, leading to a certain error percentage in the compiled data. The maintenance on some installation may be of better quality than others. To account for this issue, OREDA provides standard deviations, upper and lower percentiles in addition to the mean failure rate. OREDA have been collecting data since the 1980s, and uses all of the data they have collected since by using a weightage formula. This formula gives most weight to the most recent and reliable data as equipment has become better over the years. Despite these uncertainties, OREDA provide the most reliable reliability data available, due to the collaboration across many companies and the data provided is based on a representative selection. The data has been controlled by a proficient group and filtered to give the most accurate reliability data possible. Data in OREDA is presented in a structured way, and by separating main groups such as pumps, engines, valves, etc., into subgroups with different types of pumps, engines, valves, etc. This makes it easy for the user to find a similar subgroup of equipment he/she wants the reliability data for.

From SAP functional location, equipment, and material attributes has been exported in order to build the Access database. When implementing the framework it is recommended to use live data, or update the data regularly to account for new materials and updated stock levels, etc. That will improve the reliability of the results. Prices of the materials updated as an average in SAP for each purchase, as the price can vary from supplier to supplier and time to time. For more up to date attributes in SAP it is recommended to implement the same function for lead times in SAP. This is not currently used and the data on lead times are generically set to 70 days. By updating this data for each purchase, the framework would be less time consuming because the user would not have to find lead times for each material.

Bolette Dolphin has been in operation for approximately one year. This makes the data regarding failure rates uncertain. When the fault reports are made in SAP it is important that the correct functional location is used, and if the same failure happen several times it should be recorded against the same functional location each time. The quality of failure reports in SAP is varying depending on the author of the failure reports. To resolve this, the crews need more training in SAP. With more training the historic quality of maintenance will improve thus improving the foundation for determining spare part inventories based on failure rates from the MODU the spare parts will be used as well as improving maintenance strategy. Today DD has too limited data to use SAP as a main source for failure rates. Historic consumption data may be used as a failure rate for materials, as it is known how many of each materials that are installed in the MODU. The consumption can be divided on number of hours in operation and number installed to find the failure rate of the specific material. The consumption will widely vary if the material is used in different machines with different operating mode, this makes the historic consumption data too uncertain to use as failure rate in most cases.

7.6.1 Data format

All of the input data is stored in the basis tables. As these are designed in Access it makes data import easier if the export from SAP matches the design of these tables. The advantage of designing the tables in Access is that it is easy to update large amounts of data by the use of queries, or editing the fields with regard to data format.

When working in Access, it is important to name tables, queries, forms, and objects in forms logically. This makes referencing within the database much easier. With logical names troubleshooting is easier, as error messages often include the object names.

7.7 Further work with framework

The proposed framework provides lower stock levels than the current stock levels, and a framework that easily can be implemented across the organization. There is however possible to further improve the framework.

Before utilizing the framework it is necessary that there exist some data regarding the materials to analyze. The minimum requirement is that the material number and description and belong to a functional location which is consequence classified, as the rest can be entered manually when using the forms. If DD decides to invest in new equipment, this framework cannot be used for deciding the spare part levels, before the new functional location has been consequence classified, and material numbers have been created for the BOM. By creating a framework that can be used independently of SAP, further savings could be made.

When DD gets more MODUs up and running in SAP, this framework can be used to optimize spare part stocks across the fleet. It is then possible to see which spare parts that are available on other rigs. Then it will be possible to create a pool for capital spares that can be shared across the fleet, this will in turn reduce the necessary spare parts. For this to be possible the MODUs should be within reasonable distance of each other.

Another suggestion for improving the framework is to combine the two forms, "frm_DecisionAid" and "frm_DecideSpareQuantity". It was decided to create two separate forms, to have one form for easily going through the BOM of functional location by functional location and the other for deciding quantity to stock. Due to the large number of materials not connected to BOMs, this method made it possible to have a manual form for analyzing materials not connected to a BOM.

In order to further improve the robustness of the framework a sensitivity analysis can be performed. The sensitivity analysis may further reduce uncertainties, such as uncertainties of failure rates. A sensitivity analysis will further quantify the relationships of the different parameters, and what the result of unexpected parameter values will do to the result.

Often in maintenance one has to decide whether to replace a complete unit, or replace components of the unit. In some instances it is more economic to replace components, and other instances it is more economic to replace the unit. This judgement has to be made from equipment to equipment. As an example, Statoil has a technical requirement, TR2000, regarding valves and pipes. In this technical requirement, the replacement level of different valve sizes is generalized. For example, valves of a certain type and size are only replaced by a complete valve, while larger sizes are repaired by component replacement. If such a criteria or generalization could be implemented in the framework, it would further reduce overall maintenance costs for DD.

8 Conclusion

The objective of this thesis was to create a framework DD can use for determining spare part stock levels. The framework is divided into two parts. The first part consists of deciding if the spare part should be stocked, or purchased when required. The second part is determining stock levels. The first decision is based on weighing costs of stocking and costs of stocking at failure, as well as evaluating failure probability. If it is high probability of failure during the equipment lifetime or the costs of stocking is lower than stocking at failure, the spare part should be stocked. Costs of stocking includes procurement, logistics and holding costs of the spare part. Costs of stocking at failure include costs of not having spare part available, e.g. downtime and premium of urgent orders.

To be able to make a reasoned decision for spare part stock levels parameters influencing stock levels was evaluated, and implemented in the framework. These parameters were used for a scoring system. In the framework six parameters are proposed, whereof three are attributes of the functional location the spare part belongs to, and three are attributes of the spare part. The two most important parameters were found to be number of identical parts installed and expected consumption.

With the use of the framework for deciding stock levels, it has been achieved a reduction of spare part inventory value with between 5.8% and 46%. For the choke and kill valve, the result was an increase of the spare part inventory value of 9%.

In the current situation analysis many materials were found to be overstocked. In order to focus on keeping spare part stocks within the defined limits a form to get a list of the overstocked materials was designed. This list will help in reducing stocks by introducing purchasing stops, or get a new evaluation of the defined limits.

The framework proposed in this thesis may be used to improve business processes, continuous improvement is a trademark of a successful organization.

By implementing a framework that provides a reduction of 10% of the spare part inventory, DD will in a better position to handle rough market conditions than their competitors. If a spare part inventory is assumed to be roughly $20 million for each MODU, the savings across the fleet will substantial. More important than the savings is to avoid downtime, by being able to show to efficient and highly productive MODUs over time DD will fulfill their vision to be the preferred drilling contractor.

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10 Appendices

Appendix A – SFI groups

In this appendix, all SFI groups seen in figure 4-2, regarding spare parts connected to SFI groups, are named. The SFI groups are sorted by value, with highest value as number one.

1. 313 – Rotary table, top drive and ass. equipment
2. 341 – Derrick mount vertical pipe handling systems
3. 361 – Deck cranes
4. 304 – Drill string heave compensator
5. 325 – Mud supply
6. 362 – Pipe handling cranes
7. 311 – Drilling eq. Instrumentation and control
8. 342 – Drill floor tubular handling equipment
9. 651 – Main diesel generator engines
10. 635 – Azimuth thrusters
11. 317 – Misc. Drill floor equipment and systems
12. 721 – Seawater cooling system
13. 324 – Mud mixing and storage
14. 343 – Power packs for pipe/tubular handling
15. 312 – Draw works & machinery
16. 336 – Choke & kill systems including mud/gas separator
17. 315 – H.P. hoses, chiksans, piping and valves
18. 733 – General air system
19. 364 – Bop transportation system
20. 314 – Tensioning systems
21. 332 – Blowout preventer Stack
22. 365 – Utility hoists
23. 303 – Travelling equipment
24. 326 – Mud solids control
25. 347 – Misc. Eq. For Pipe/Tubular Handling
26. 702 – Fuel oil purification plants
27. 345 – Elevators
28. 722 – Freshwater and other cooling systems
29. 337 – Misc well control related equipment
30. 335 – Riser sys. Incl. C&K and booster line
31. 481 – Bulk loading stations
32. 813 – Fire/Wash down system emr. Fire pumps
33. 712 – Lube oil purification plants
34. 305 – Misc. derrick systems
35. 321 – Bulk storage and transfer systems
36. 731 – Starting air systems (High pressure)
37. 744 – Exhaust gas sys for diesel engines, etc.
38. 741 – Fresh air intakes (not ventilation)
39. 571 – Ventilation, air-con systems for acc, etc.

40. 801 – Ballast systems and solid ballast
41. 803 – Bilge system
42. 582 – Sanitary discharge system, drainage systems
43. 323 – Mud additive system
44. 821 – Air & sounding sys from tanks to deck
45. 445 – Garbage disposal plants
46. 574 – Vent, Air-Con for Machinery Spaces
47. 831 – Special Common Hyd. Oil Systems
48. 316 – Wire Lines
49. 566 – Helicopter Platform with Equipment
50. 454 – Mobile Transport And Handling Equipment
51. 701 – Fuel Oil transfer And Drain Systems
52. 665 – Emergency Diesel Generator Engines
53. 578 – Vent, Air-Con Sys in Drill Machine Rooms
54. 289 – Cathodic Protection, Internal
55. 584 – Drinking Water System and Coolers
56. 572 – Vent, Air-Con Systems for Prov. Rooms
57. 327 – Drill water System
58. 734 – Instrument air supply system
59. 551 – Galley Machinery
60. 322 – Bulk Air System
61. 452 – Travelling Crane and Lifting, Etc.
62. 501 – Lifeboats With Equipment
63. 865 – Transformers
64. 761 – Distilled and Make Up Water Systems
65. 852 – Automation sys for watertight integrity
66. 713 – L.O. Sys for Propuls Mach & Transmission
67. 711 – Lube Oil transfer And Drain Systems
68. 408 – Dynamic Positioning System (DP)
69. 851 – Integrated control & monitoring system
70. 384 – Misc. Instruments and Auxiliary System

Appendix B – Walkthrough of frm_DecisionAid

This appendix shows the use of the frm_DecisionAid step by step, showing the process of deciding to stock a material or not.

The first image when the form is opened is shown in Figure 0-1.

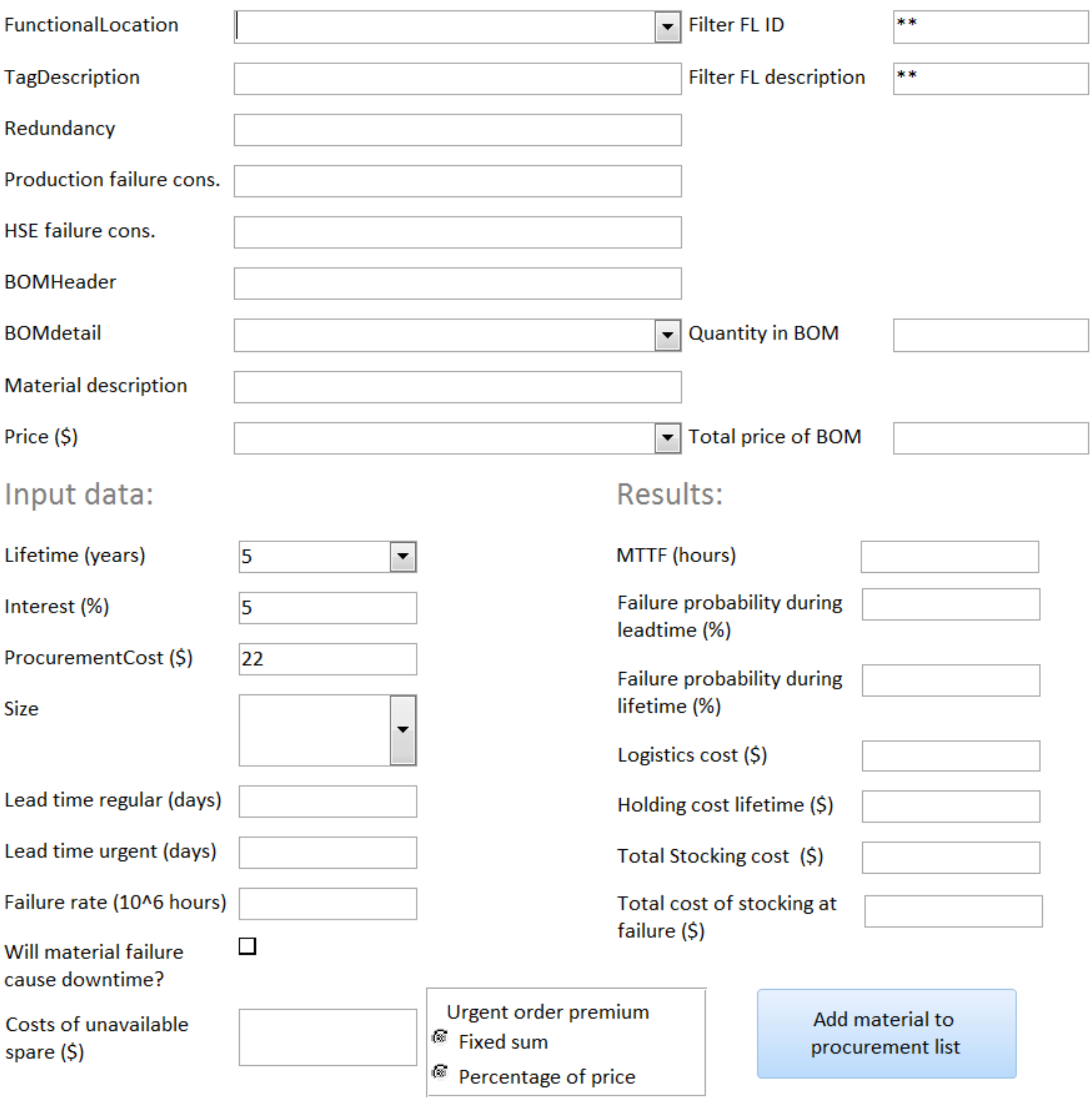

Figure 0-1 Form view of "frm_DecisionAid"

By writing in the filter boxed, the results shown in the drop-down list is reduced.

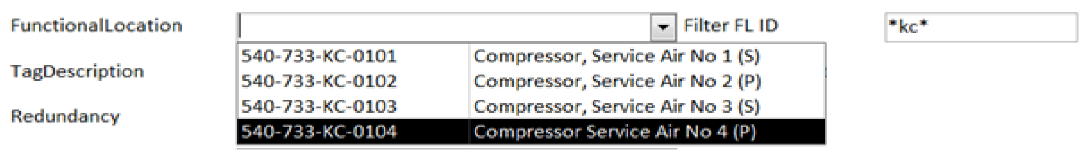

Figure 0-2 Filtered results

When choosing a functional location, the form will select information associated with the compressor.

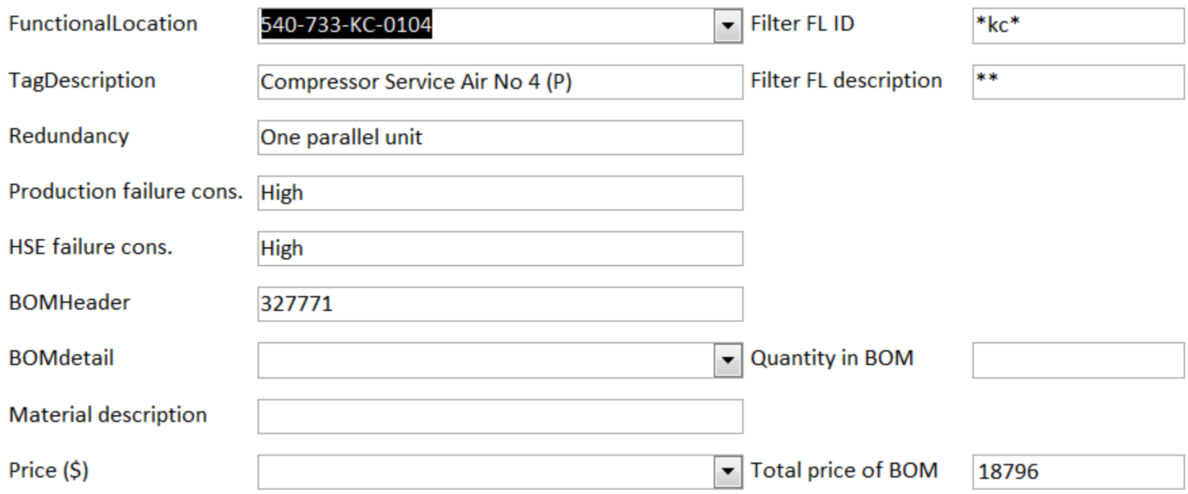

Figure 0-3 Automatic retrieved data after selecting functional location.

After choosing functional location, spare parts can be selected from the drop-down list of BOMdetail.

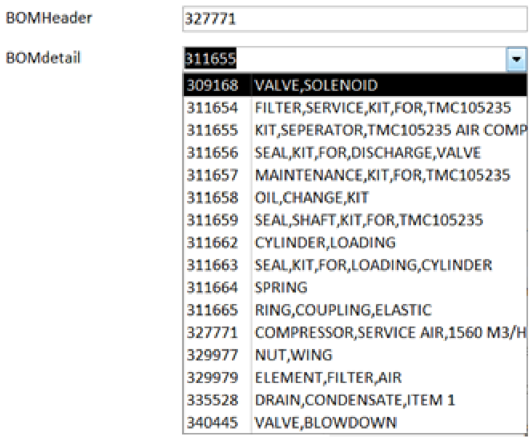

Figure 0-4 Drop-down list of associated spare parts

Material 311655, Kit, Separator, TMC105235 Air Comp is chosen. After choosing material to analyze, input data must be filled out. Lifetime is the expected number of years the equipment can operate before a major overhaul. This is by default 5, but can be changed manually. Interest is the calculation interest for tied capital cost, this is set to 5 by default, but can be changed manually. Procurement costs are set to $22, but can be changed. Size of the material can be chosen from the drop-down list with alternatives; small, medium and large. This influences the holding and logistics cost. Both urgent and regular lead time must be filled out, as it is used for calculating costs of stocking at failure. Failure rate is found from OREDA.

As there are no failure rate for the separator in OREDA, the failure rate for a compressor is used. When the failure rate is filled out, the form automatically calculates MTTF, and failure probabilities. If material failure causes downtime, the checkbox must be checked, if not it remains unchecked. Costs of unavailable spare must be entered, this is individual for each functional location and is based on experience. The premium of urgent orders can be entered as a percentage or a fixed sum. This can be chosen by clicking the radio buttons.

Then all results available and the form will look similar to Figure 0-5.

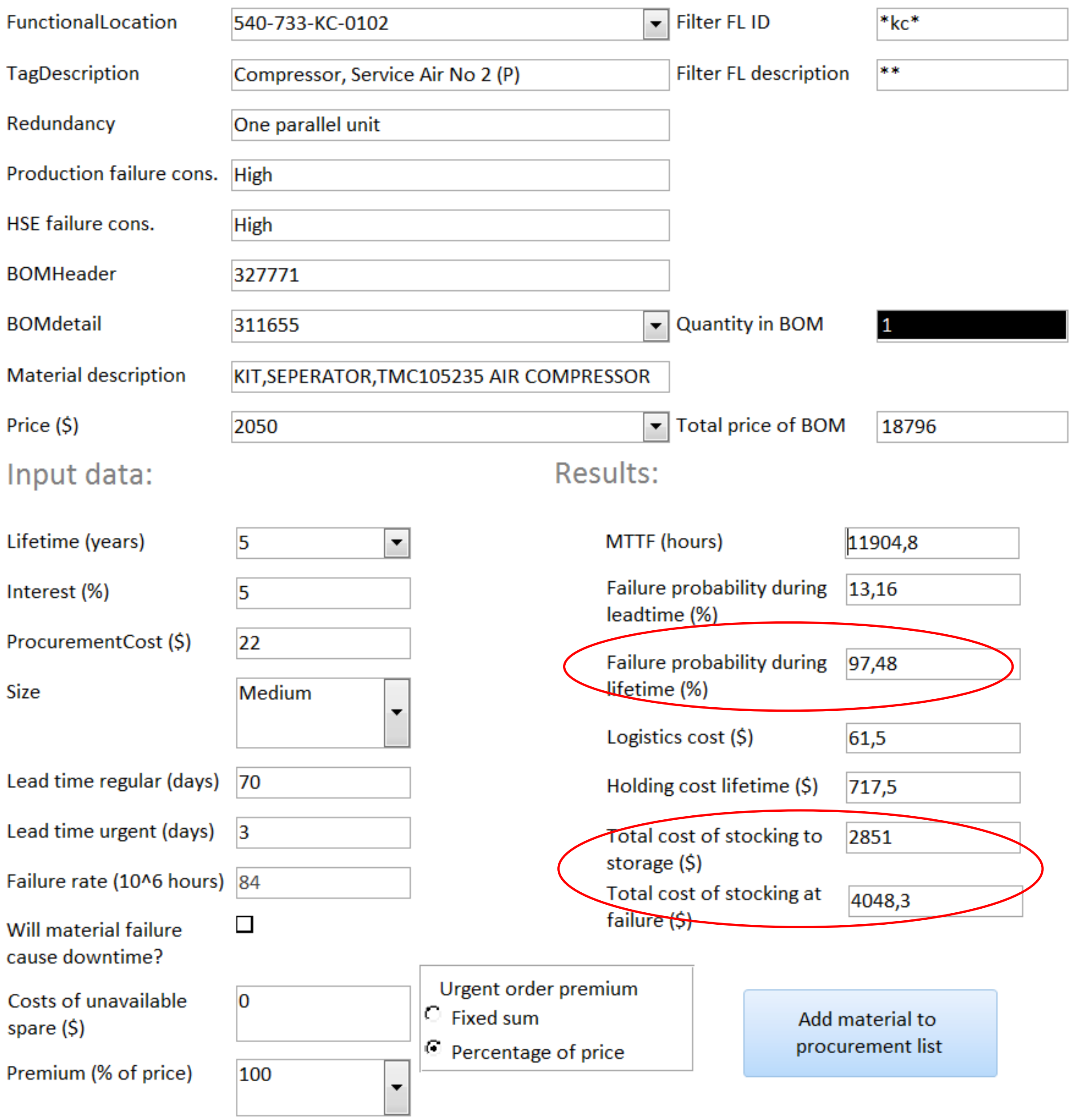

Figure 0-5 Filled out form

Now that the form is completely filled out, it can be seen that the costs of stocking this material at failure is higher than stocking it to storage, as well as there is a high probability of failure causing need for this material. This means that the material should be stocked. By clicking the blue button the material will be added to the table "tbl_ShoppingCart", and the quantity has to be decided with the use of form "frm_DecideSpareQuantity".

Appendix C – Walkthrough of frm_DecideSpareQuantity

This appendix shows step by step how to use the form “frm_DecideSpareQuantity”. This form is linked to table “tbl_ShoppingCart”. That means that the material drop down list, shows all materials which is in that tlable. The materials are added to table “tbl_ShoppingCart” from form “frm_DecisionAid”.

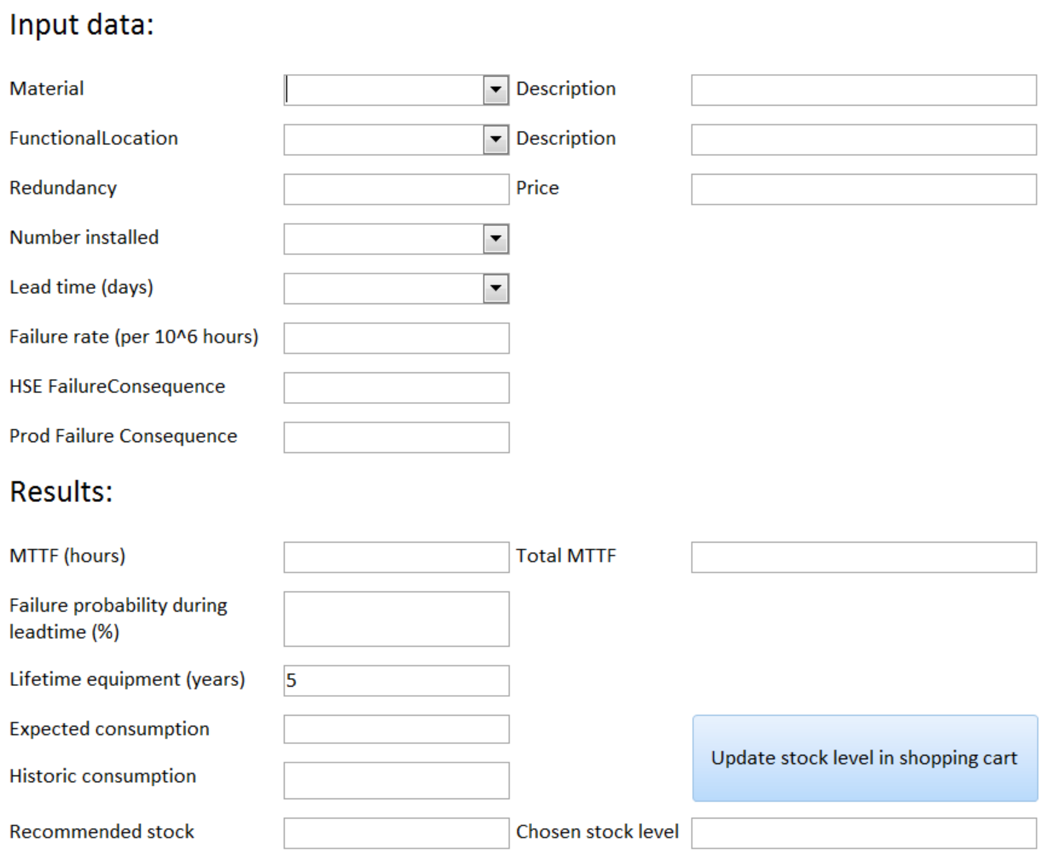

Figure 0-1 Blank “frm_DecideSpareQuantity” form

When pressing the arrow, all materials in the table appear and a material can be selected.

Figure 0-2 Choosing material from dropdown list.

Material 311655, and functional location 540-733-KC-0101 is chosen from the functional location drop-down list. Then the fields; price, failure rate, HSE and prod failure consequence, MTTF, and historic consumption will be updated according to the information stored in the database. Then the form will look like figure.

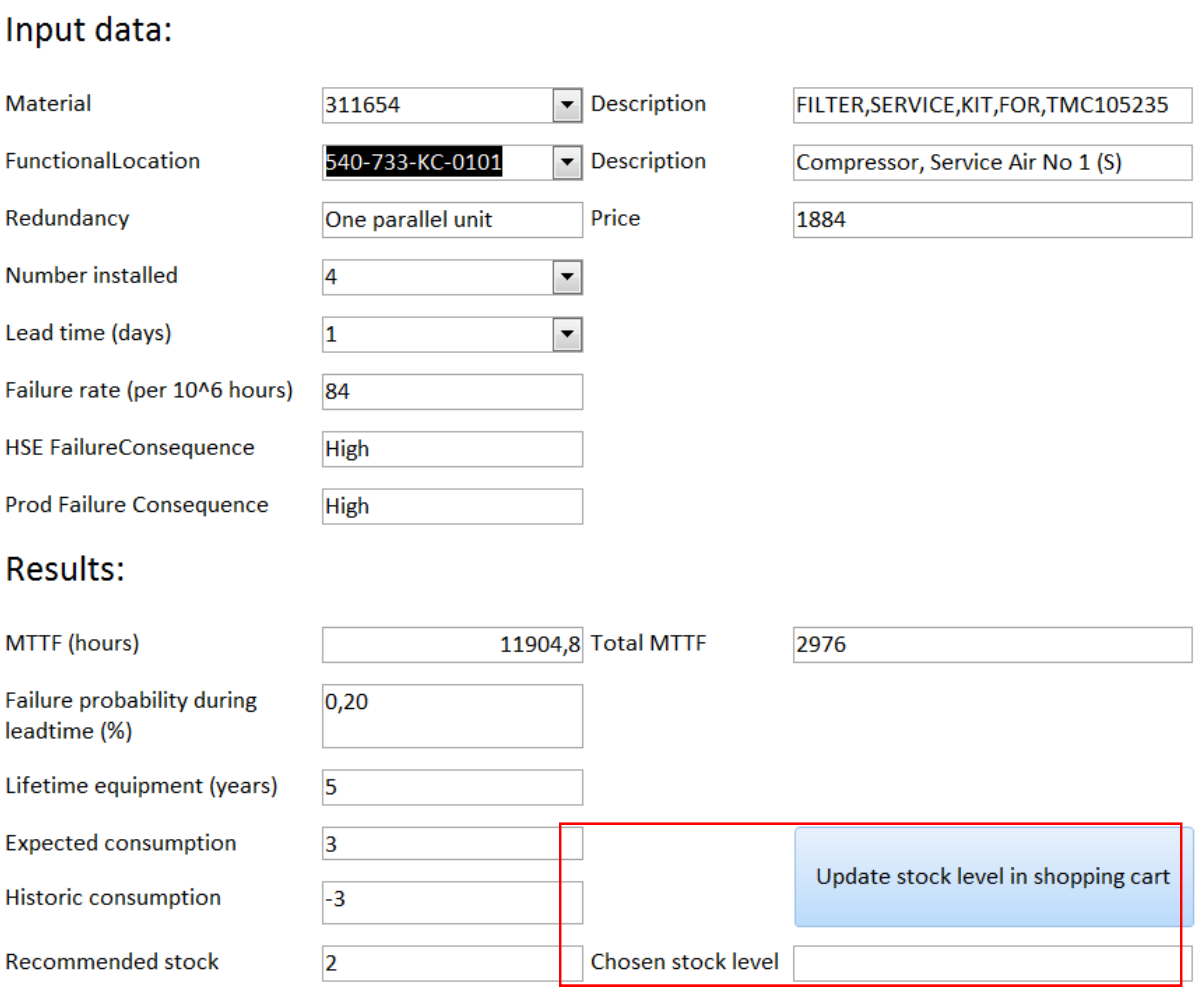

Figure 0-3 Almost complete "frm_DecideSpareQuantity" form. The final step is to choose stock level and press the blue button.

The user has to manually select number installed and lead time, by choosing from these drop-down lists. It is also possible to enter this information manually, if the options are incorrect for some reason. When all fields under input data is entered, all results will be shown similarly to Figure 0-3.

Then the only remaining step is to enter chosen stock level, and press the blue button and "tbl_ShoppingCart" will be updated with the chosen stock level.

Appendix D – Design of all queries

In order to easily be able to reproduce the Access database and its queries, this appendix displays the design view of all queries. The SQL is pasted underneath the figures. The SQL code can be copied into the SQL view in access to reproduce the query.

qry_AppendOverstock_All

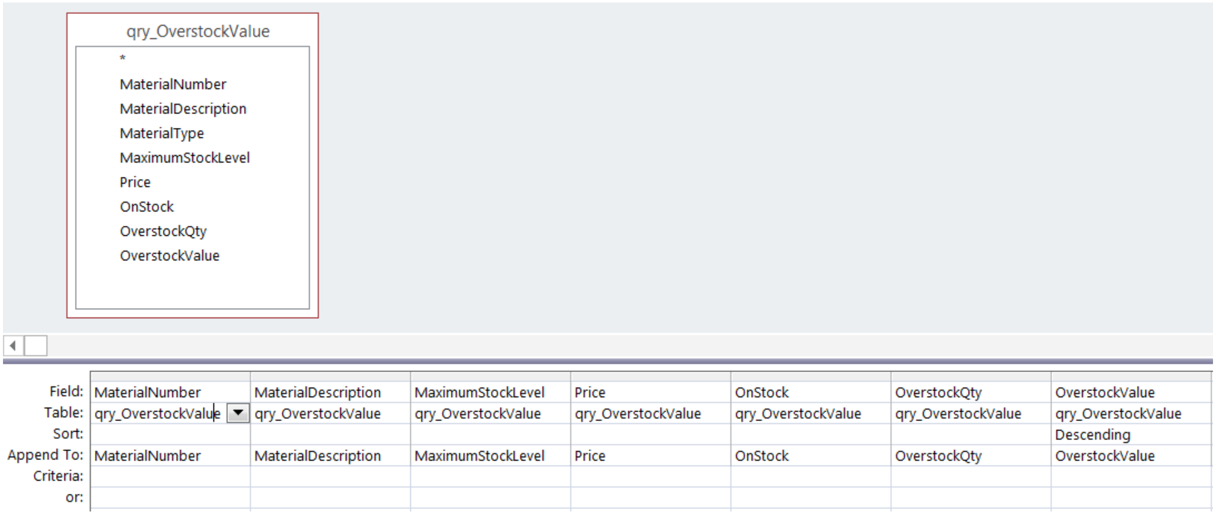

Figure 0-1 Design view of query qry_AppendOverstock_All

INSERT INTO tbl_OverstockList (MaterialNumber, MaterialDescription, MaximumStockLevel, Price, OnStock, OverstockQty, OverstockValue)

SELECT DISTINCT qry_OverstockValue.MaterialNumber, qry_OverstockValue.MaterialDescription, qry_OverstockValue.MaximumStockLevel, qry_OverstockValue.Price, qry_OverstockValue.OnStock, qry_OverstockValue.OverstockQty, qry_OverstockValue.OverstockValue

FROM qry_OverstockValue

ORDER BY qry_OverstockValue.OverstockValue DESC;

qry_AppendOverstock_qtysort

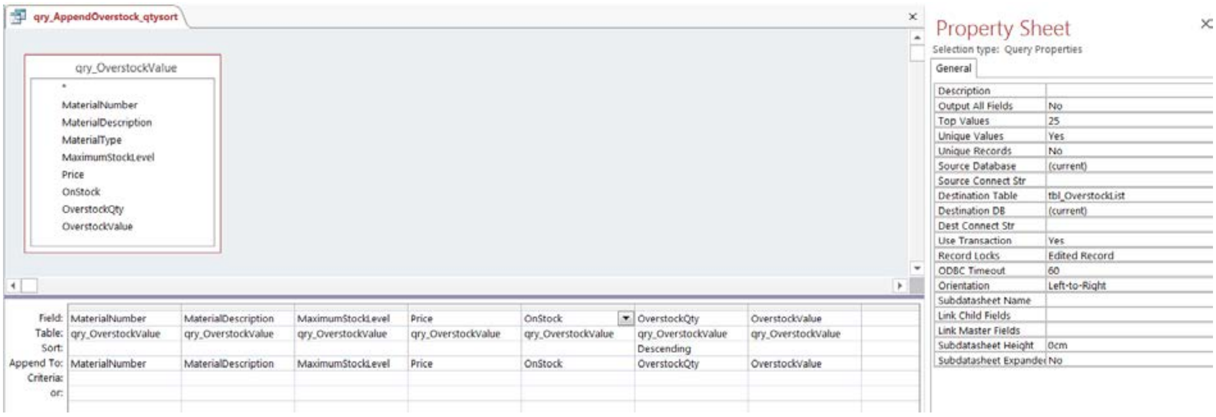

Figure 0-2 Design view of query "qry_AppendOverstock_qtysort"

INSERT INTO tbl_OverstockList (MaterialNumber, MaterialDescription, MaximumStockLevel, Price, OnStock, OverstockQty, OverstockValue)

SELECT DISTINCT TOP 25 qry_OverstockValue.MaterialNumber, qry_OverstockValue.MaterialDescription, qry_OverstockValue.MaximumStockLevel, qry_OverstockValue.Price, qry_OverstockValue.OnStock, qry_OverstockValue.OverstockQty, qry_OverstockValue.OverstockValue

FROM qry_OverstockValue

ORDER BY qry_OverstockValue.OverstockQty DESC;

qry_AppendOverstock_valuesort

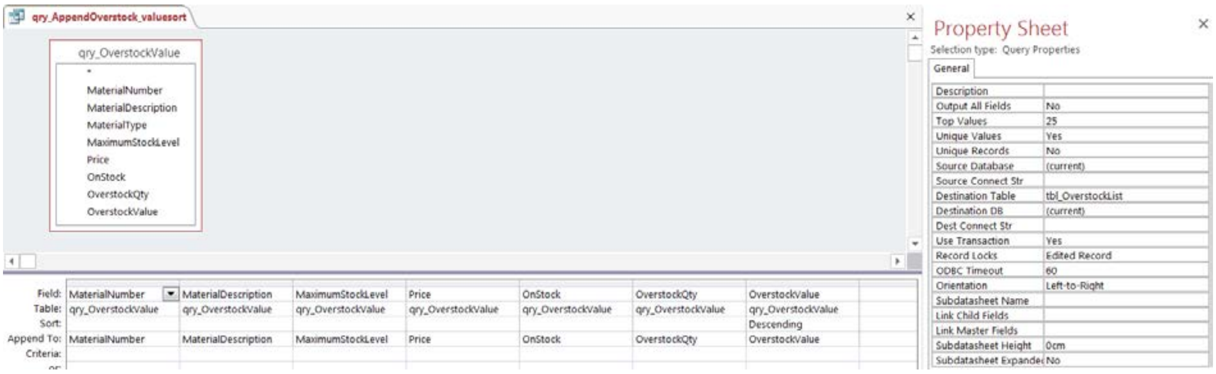

Figure 0-3 Design view of query "qry_AppendOverstock_valuesort"

INSERT INTO tbl_OverstockList (MaterialNumber, MaterialDescription, MaximumStockLevel, Price, OnStock, OverstockQty, OverstockValue)

SELECT DISTINCT TOP 25 qry_OverstockValue.MaterialNumber, qry_OverstockValue.MaterialDescription, qry_OverstockValue.MaximumStockLevel, qry_OverstockValue.Price, qry_OverstockValue.OnStock, qry_OverstockValue.OverstockQty, qry_OverstockValue.OverstockValue

FROM qry_OverstockValue

ORDER BY qry_OverstockValue.OverstockValue DESC;

qry_AppendShoppingCart

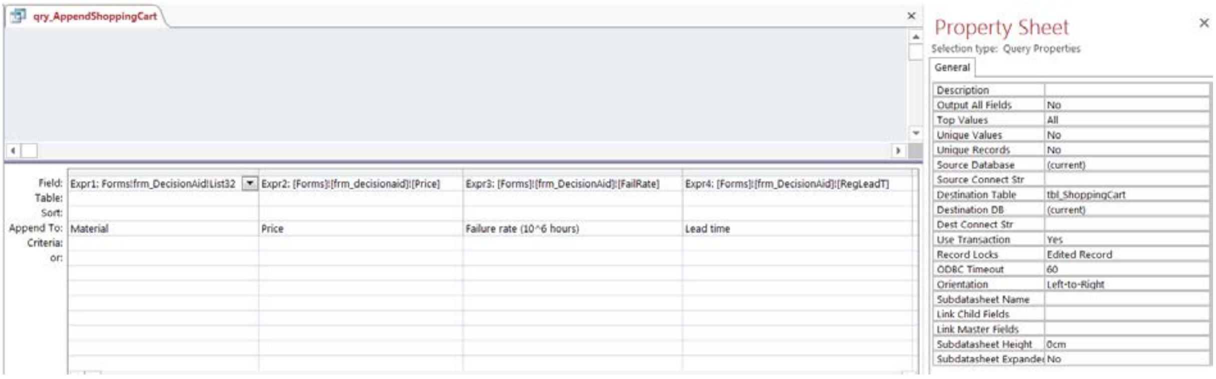

Figure 0-4 Design view of query "qry_AppendShoppingCartt"

INSERT INTO tbl_ShoppingCart (Material, Price, [Failure rate (10^6 hours)], [Lead time])

SELECT Forms!frm_DecisionAid!List32 AS Expr1, [Forms]![frm_decisionaid]![Price] AS Expr2, [Forms]![frm_DecisionAid]![FailRate] AS Expr3, [Forms]![frm_DecisionAid]![RegLeadT] AS Expr4;

qry_AppendShoppingCartManual

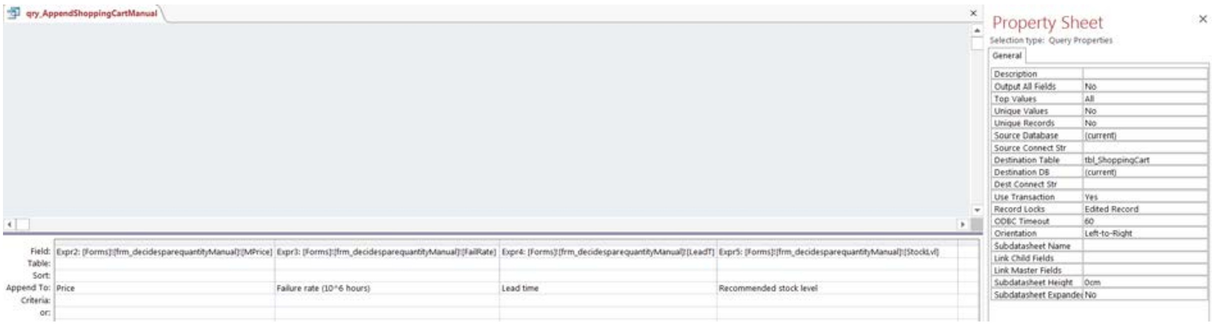

Figure 0-5 Design view of query "qry_AppendShoppingCartManual"

INSERT INTO tbl_ShoppingCart (Material, Price, [Failure rate (10^6 hours)], [Lead time], [Recommended stock level])

SELECT [Forms]![frm_decidesparequantityManual]![InputM] AS Expr1, [Forms]![frm_decidesparequantityManual]![MPrice] AS Expr2, [Forms]![frm_decidesparequantityManual]![FailRate] AS Expr3, [Forms]![frm_decidesparequantityManual]![LeadT] AS Expr4, [Forms]![frm_decidesparequantityManual]![StockLvl] AS Expr5;

qry_EmptyOverstockList

Figure 0-6 Design view of query "qry_EmptyOverstockList"

DELETE DISTINCTROW tbl_OverstockList.*

FROM tbl_OverstockList;

qry_FL_DecisionAid

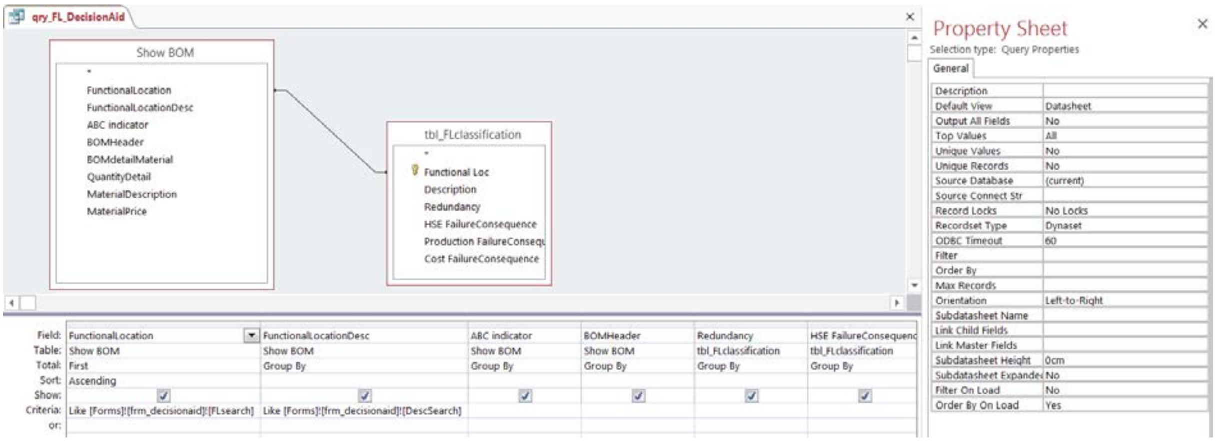

Figure 0-7 Design view of query "qry_FL_DecisionAid"

SELECT First([qry_ShowBOM].FunctionalLocation) AS FirstOfFunctionalLocation, [qry_ShowBOM].FunctionalLocationDesc, [qry_ShowBOM].[ABC indicator], [qry_ShowBOM].BOMHeader, tbl_FLclassification.Redundancy, tbl_FLclassification.[HSE FailureConsequence], tbl_FLclassification.[Production FailureConsequence]

FROM [qry_ShowBOM] INNER JOIN tbl_FLclassification ON [qry_ShowBOM].FunctionalLocation = tbl_FLclassification.[Functional Loc]

GROUP BY [qry_ShowBOM].FunctionalLocationDesc, [qry_ShowBOM].[ABC indicator], [qry_ShowBOM].BOMHeader, tbl_FLclassification.Redundancy, tbl_FLclassification.[HSE FailureConsequence], tbl_FLclassification.[Production FailureConsequence]

HAVING (((First([qry_ShowBOM].FunctionalLocation)) Like [Forms]![frm_decisionaid]![FLsearch]) AND (([qry_ShowBOM].FunctionalLocationDesc) Like [Forms]![frm_decisionaid]![DescSearch]))

ORDER BY First([qry_ShowBOM].FunctionalLocation);

qry_NoInstDetailMaterial

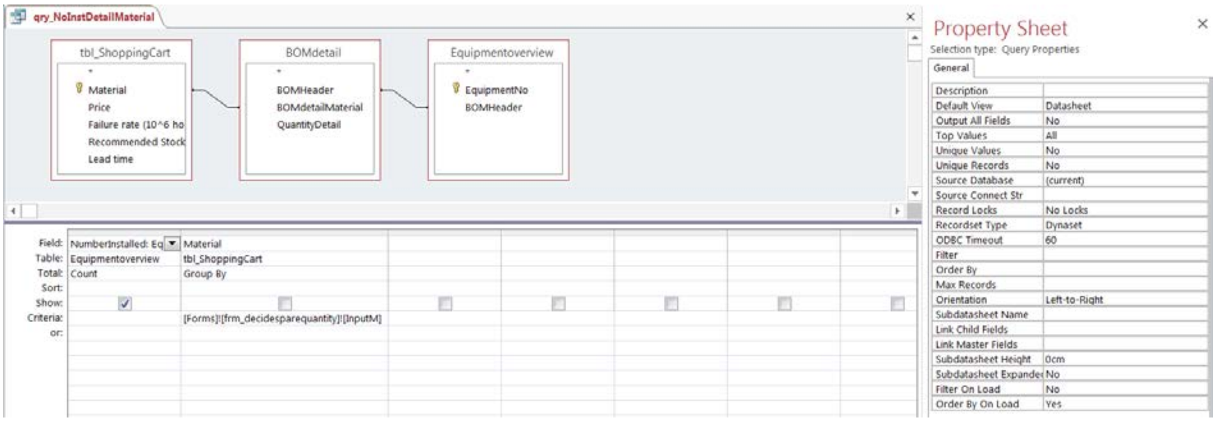

Figure 0-8 Design view of query "qry_No_InstDetailMaterial"

SELECT Count(Equipmentoverview.EquipmentNo) AS NumberInstalled

FROM tbl_ShoppingCart INNER JOIN (BOMdetail INNER JOIN Equipmentoverview ON BOMdetail.BOMHeader = Equipmentoverview.BOMHeader) ON tbl_ShoppingCart.Material = BOMdetail.BOMdetailMaterial

GROUP BY tbl_ShoppingCart.Material

HAVING (((tbl_ShoppingCart.Material)=[Forms]![frm_decidesparequantity]![InputM]));

qry_NoInstHeaderMaterial

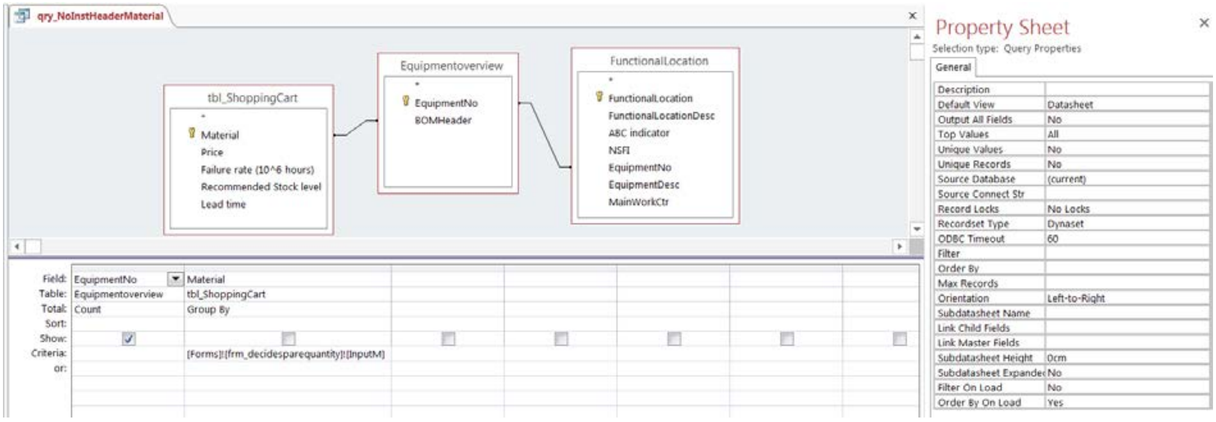

Figure 0-9 Design view of query "qry_No_InstHeaderMaterial"

SELECT Count(Equipmentoverview.EquipmentNo) AS CountOfEquipmentNo

FROM tbl_ShoppingCart INNER JOIN (FunctionalLocation INNER JOIN Equipmentoverview ON FunctionalLocation.EquipmentNo = Equipmentoverview.EquipmentNo) ON tbl_ShoppingCart.Material = Equipmentoverview.BOMHeader

GROUP BY tbl_ShoppingCart.Material

HAVING (((tbl_ShoppingCart.Material)=[Forms]![frm_decidesparequantity]![InputM]));

qry_OverstockFLsorted

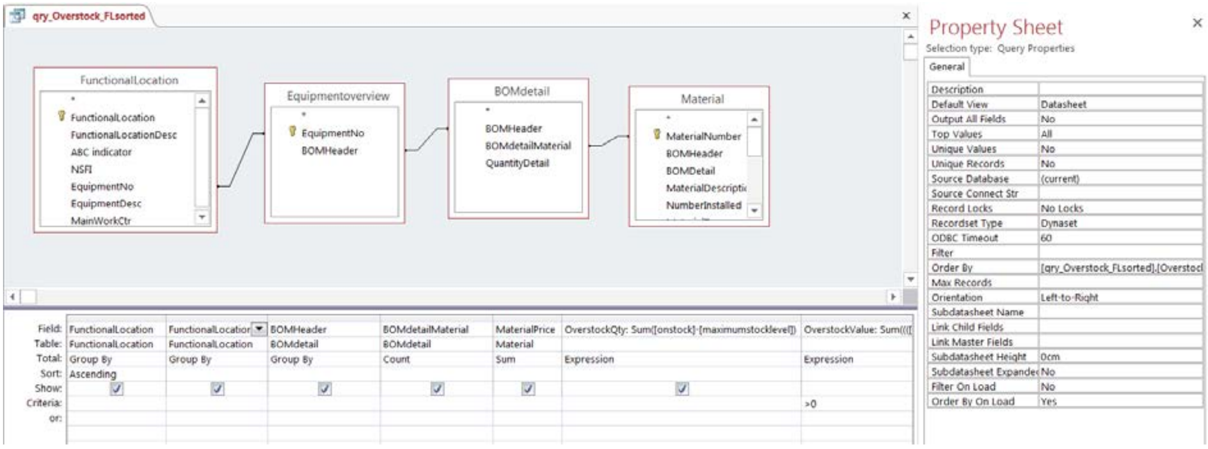

Figure 0-10 Design view of query "qry_OverstockFLsorted"

SELECT FunctionalLocation.FunctionalLocation, FunctionalLocation.FunctionalLocationDesc, BOMdetail.BOMHeader, Count(BOMdetail.BOMdetailMaterial) AS CountOfBOMdetailMaterial, Sum(Material.MaterialPrice) AS SumOfMaterialPrice, Sum([onstock]-[maximumstocklevel]) AS OverstockQty, Sum((([Onstock]-[maximumstocklevel])*[materialprice])) AS OverstockValue

FROM ((FunctionalLocation INNER JOIN Equipmentoverview ON FunctionalLocation.EquipmentNo = Equipmentoverview.EquipmentNo) INNER JOIN BOMdetail ON Equipmentoverview.[BOMHeader] = BOMdetail.BOMHeader) INNER JOIN Material ON BOMdetail.BOMdetailMaterial = Material.MaterialNumber

GROUP BY FunctionalLocation.FunctionalLocation, FunctionalLocation.FunctionalLocationDesc, BOMdetail.BOMHeader

HAVING (((Sum((([Onstock]-[maximumstocklevel])*[materialprice])))>0))

ORDER BY FunctionalLocation.FunctionalLocation;

qry_OverstockValue

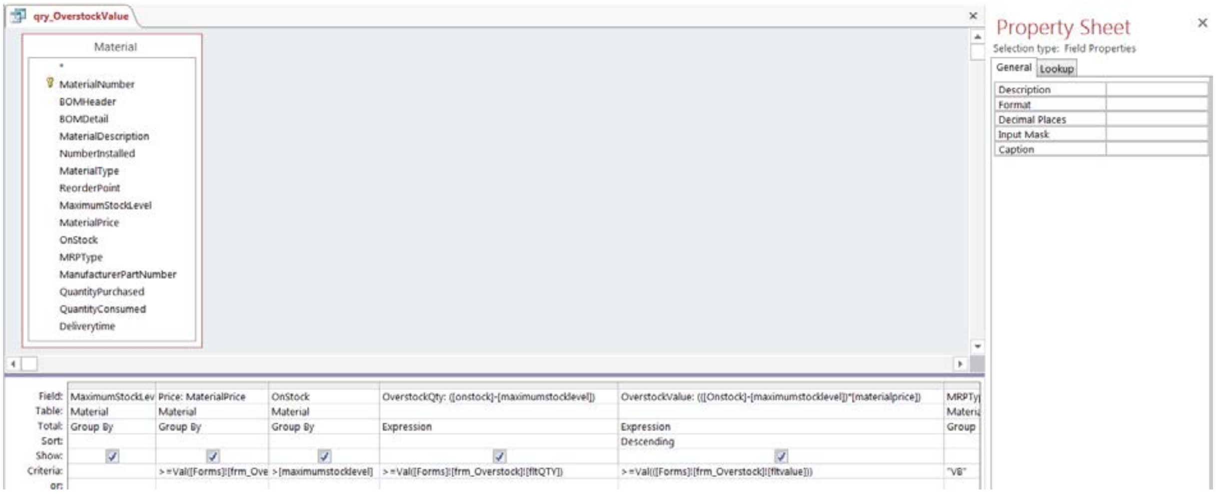

Figure 0-11 Design view of query “qry_OverstockValue"

SELECT Material.MaterialNumber, Material.MaterialDescription, Material.MaterialType, Material.MaximumStockLevel, Material.MaterialPrice AS Price, Material.OnStock, ([onstock]-[maximumstocklevel]) AS OverstockQty, (([Onstock]-[maximumstocklevel])*[materialprice]) AS OverstockValue

FROM Material

GROUP BY Material.MaterialNumber, Material.MaterialDescription, Material.MaterialType, Material.MaximumStockLevel, Material.MaterialPrice, Material.OnStock, Material.MRPType

HAVING (((Material.MaterialPrice)>=Val([Forms]![frm_Overstock]![fltPrice])) AND ((Material.OnStock)>[maximumstocklevel]) AND ((([onstock]-[maximumstocklevel]))>=Val([Forms]![frm_Overstock]![fltQTY])) AND (((([Onstock]-[maximumstocklevel])*[materialprice]))>=Val(([Forms]![frm_Overstock]![fltvalue]))) AND ((Material.MRPType)="VB"))

ORDER BY (([Onstock]-[maximumstocklevel])*[materialprice]) DESC;

qry_OverstockValueTotal

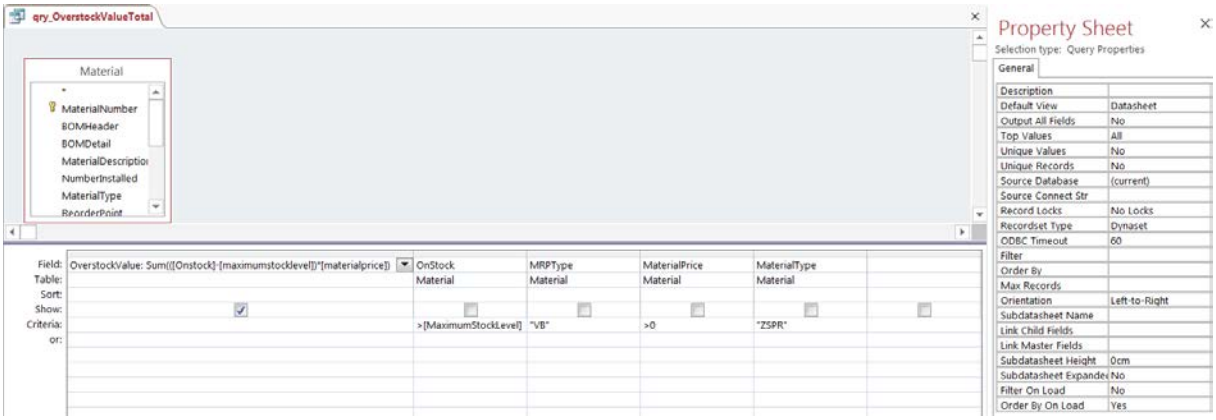

Figure 0-12 Design view of query “qry_OverstockValueTotal"

SELECT Sum(([Onstock]-[maximumstocklevel])*[materialprice]) AS OverstockValue

FROM Material

WHERE (((Material.OnStock)>[MaximumStockLevel]) AND ((Material.MRPType)="VB") AND ((Material.MaterialPrice)>0) AND ((Material.MaterialType)="ZSPR"));

qry_Shoppingcart_vs_actualstock

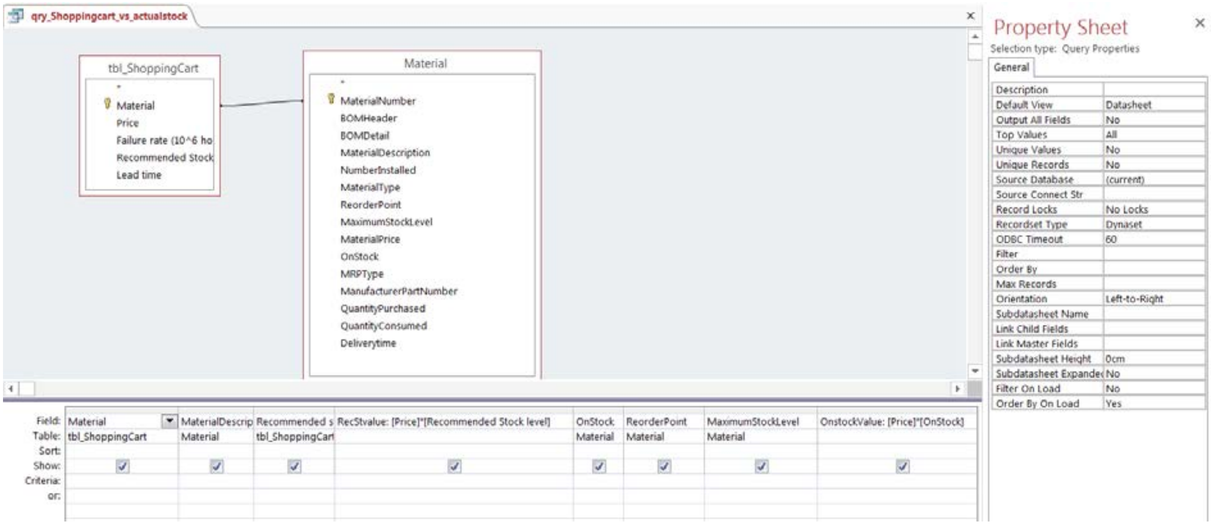

Figure 0-13 Design view of query “qry_ShoppingCart_vs_actualstock"

SELECT tbl_ShoppingCart.Material, Material.MaterialDescription, tbl_ShoppingCart.[Recommended stock level], [Price]*[Recommended Stock level] AS RecStvalue, Material.OnStock, Material.ReorderPoint, Material.MaximumStockLevel, [Price]*[OnStock] AS OnstockValue, tbl_ShoppingCart.Price

FROM tbl_ShoppingCart INNER JOIN Material ON tbl_ShoppingCart.Material = Material.MaterialNumber;

qry_ValueofBOM

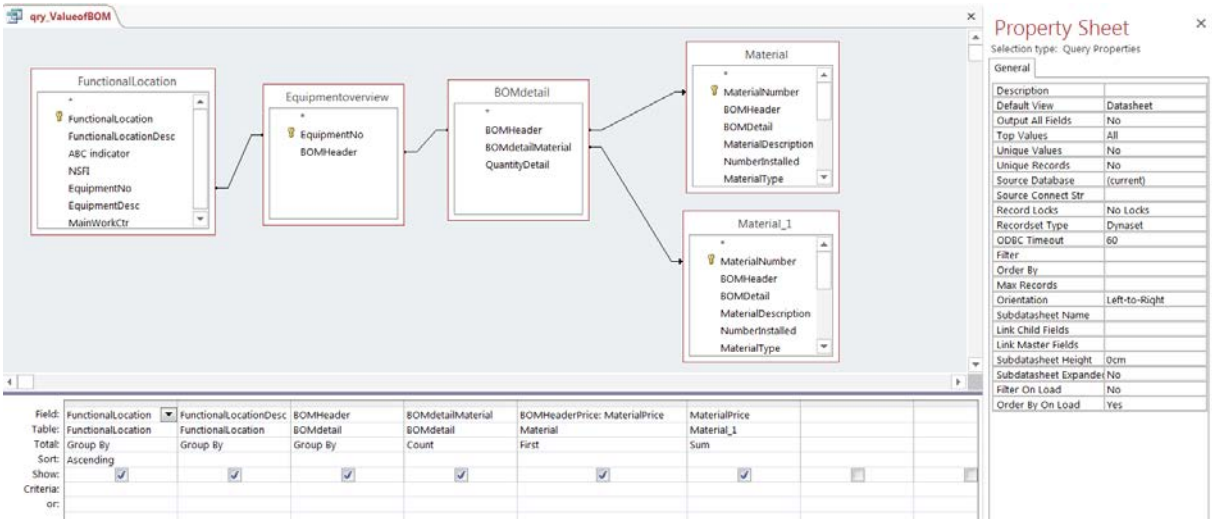

Figure 0-14 Design view of query “qry_ValueofBOM"

SELECT FunctionalLocation.FunctionalLocation, FunctionalLocation.FunctionalLocationDesc, BOMdetail.BOMHeader, Count(BOMdetail.BOMdetailMaterial) AS CountOfBOMdetailMaterial, First(Material.MaterialPrice) AS BOMHeaderPrice, Sum(Material_1.MaterialPrice) AS SumOfMaterialPrice

FROM (((FunctionalLocation INNER JOIN Equipmentoverview ON FunctionalLocation.EquipmentNo = Equipmentoverview.EquipmentNo) INNER JOIN BOMdetail ON Equipmentoverview.[BOMHeader] = BOMdetail.BOMHeader) LEFT JOIN Material ON BOMdetail.BOMHeader = Material.MaterialNumber) LEFT JOIN Material AS Material_1 ON BOMdetail.BOMdetailMaterial = Material_1.MaterialNumber

GROUP BY FunctionalLocation.FunctionalLocation, FunctionalLocation.FunctionalLocationDesc, BOMdetail.BOMHeader

ORDER BY FunctionalLocation.FunctionalLocation;

qry_ShowBOM

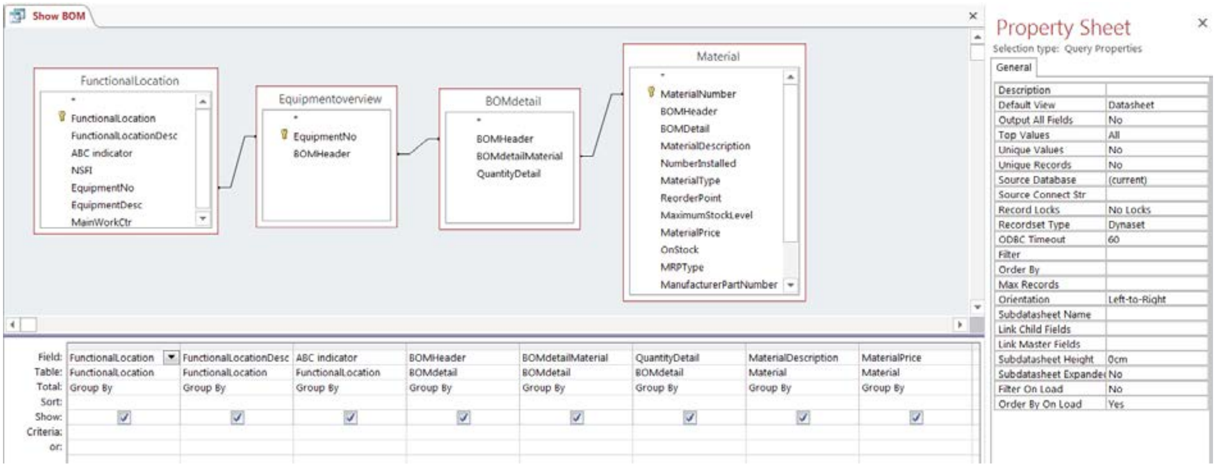

Figure 0-15 Design view of query "qry_ShowBOM"

SELECT FunctionalLocation.FunctionalLocation, FunctionalLocation.FunctionalLocationDesc, FunctionalLocation.[ABC indicator], BOMdetail.BOMHeader, BOMdetail.BOMdetailMaterial, BOMdetail.QuantityDetail, Material.MaterialDescription, Material.MaterialPrice

FROM ((FunctionalLocation INNER JOIN Equipmentoverview ON FunctionalLocation.EquipmentNo = Equipmentoverview.EquipmentNo) INNER JOIN BOMdetail ON Equipmentoverview.[BOMHeader] = BOMdetail.BOMHeader) INNER JOIN Material ON BOMdetail.BOMdetailMaterial = Material.MaterialNumber

GROUP BY FunctionalLocation.FunctionalLocation, FunctionalLocation.FunctionalLocationDesc, FunctionalLocation.[ABC indicator], BOMdetail.BOMHeader, BOMdetail.BOMdetailMaterial, BOMdetail.QuantityDetail, Material.MaterialDescription, Material.MaterialPrice;

qry_UpdateQtyShoppingCart

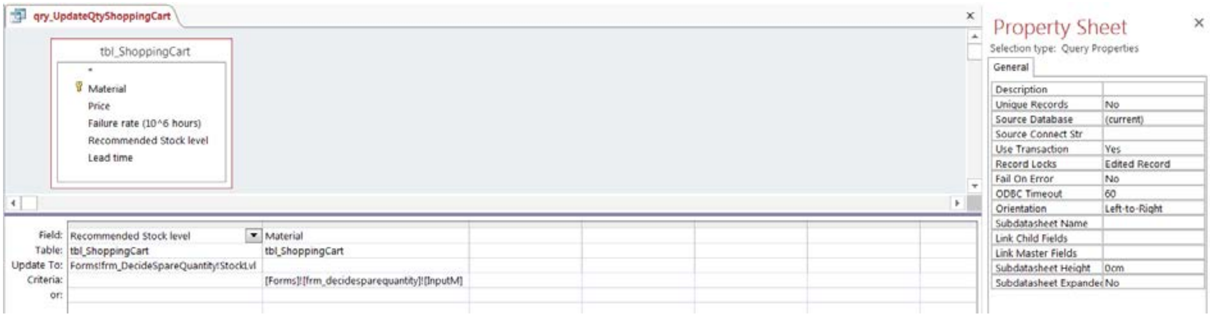

Figure 0-16 Design view of query “qry_UpdateQtyShoppingCart"

UPDATE tbl_ShoppingCart SET tbl_ShoppingCart.[Recommended Stock level] = Forms!frm_DecideSpareQuantity!StockLvl

WHERE (((tbl_ShoppingCart.Material)=[Forms]![frm_decidesparequantity]![InputM]));

Appendix E - Database with framework

The Microsoft Access database with framework is attached to the thesis on a USB flash drive.