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Drilling rig maintenance:
an analytical study of the classification, treatment, data quality of equipment failures and related downtime.

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Table of Contents

List of tables

List of figures

Abstract

The aim of this thesis is to improve the way failures caused by insufficient maintenance are being managed and reported on drilling rigs and thereby reducing the overall downtime and related cost for the rigs.

By looking into the quality of reports for critical and non-critical failures, identifying the potential consequences of non-critical failures and identifying downtime trends and possible reasons for these we will try to make suggestions on how to improve the maintenance management.

The downtime caused by insufficient maintenance was found to be low compared to other causes, with 3rd party suppliers being the cause of a large percentage of the downtime.

After introducing first line maintenance in 2006 there is a significant decrease in the number of downtime events. The downtime is however not decreasing with the reduction of events; this is most likely because the downtime is dominated by large single events. These large single downtime events have not been reduced as successfully as the smaller with the introduction of first line maintenance. Further studies of these large downtime events should be done in order to better prevent them from occurring again in the future.

Most of the downtime was found to be caused be a small selection of equipment groups, with the main contributor being the Rotary table, top drive and associated equipment group.

Using planned downtime has shown to reduce not only the unplanned downtime, but also the overall downtime of the rig.

When studying the effect of major overhauls on two different rigs we found that it preserved a very low downtime and need for maintenance for one rig and significantly lowered both for the other rig.

The quality of the reports was studied against existing guidelines and requirements as well as the requirements during the work of this thesis. Two of the databases were found to contain data of good quality, while the third in large parts not only failed to meet the requirements in this thesis, but also the existing internal requirements of NADL. To use the databases to find any hidden downtime was found to be difficult, if not impossible. A different set of criteria's in the reports have been proposed in this thesis in order to make this possible. To increase the overall quality of the reports it was found that improved communication between receiver and sender most likely will give good results.

Abbreviations & nomenclature

NADL	North Atlantic Drilling Limited
MODU	Mobile Drilling Units
HES	Health, Environment and Safety
HSEQ	Health, Safety, Environment and Quality
DP	Dynamically Positioned
WO	Work Order
PM	Preventive Maintenance
CM	Corrective Maintenance
DODA	Daily Operations Database Application
AFE	Authorization for Financial Expenditure
RCM	Reliability Centered Maintenance
KPI	Key Performance Indicators
FMECA	Failure Mode, Effects and Criticality Analysis
SFI	Skipsteknisk Forskningsinstitutt
PSA	Petroleum Safety Authority Norway

1. Introduction

Avoiding downtime of all drilling units is important for any drilling company. Not only does such downtime have direct financial consequences, but it will also have indirect effects such as loss of reputation and desirability. Therefore; being the “class leader” in downtime will not only make each drilling operation more profitable, but also make it easier to get new contracts in the future. Having low downtime can also result in better contractual agreements since the contractor will have a more reliable time frame for the drilling operation.

In this thesis downtime is defined as any period of time where the drilling rig is delayed from performing its intended operations. There can be many different causes for a rig to experience downtime (Dew and Childers, 1989), from bad weather to equipment failure and emergencies such as fire.

One way of reducing the downtime is to optimize the maintenance of the rig and its equipment. Finding the optimal balance between cost of the maintenance and cost of downtime will maximize the financial profit.

When we talk about failures we often divide them into two classes; the critical failures and the non-critical failures. The difference between these two classifications is defined by the consequences of the failure. Critical failures have direct consequences for the ongoing operation and will result in downtime, while non-critical failures will not directly result in any downtime. As a result of this definition/classification the same failure can be critical in one stage of the operation and non-critical in another stage of the operation.

Since the critical failures have more visible and larger consequences the companies have a higher focus on these failures. The requirements to the maintenance reports, observations and data obtained from such failures are much higher than for non-critical failures. We therefore risk that potentially critical failures are poorly reported and/or ignored.

This thesis will look into the historical downtime of five different mobile operating drilling units (hereafter only called MODU). It will look for historical downtime trends, the reasons for these and possible future ways to reduce downtime. The main focus will be on downtime caused by poor or insufficient maintenance, and how equipment failures are classified, managed and reported for maintenance improvements.

All the rigs in this thesis is owned and operated by North Atlantic Drilling Limited and all operate in the North Sea.

1.1 Objectives

The aim of this thesis is to improve the way failures caused by insufficient maintenance are being managed and reported on MODU`s, and thereby reducing the overall downtime and related costs.

By looking into the quality of reports for critical and non-critical failures, identifying the potential consequences of non-critical failures and identifying downtime trends and possible reasons for these we will try to make suggestions on how to improve the maintenance management.

1.2 Limitations

This study will be using collected internal data from NADL`s five drilling rigs operating in Europe; West Alpha, West Phoenix, West Navigator, West Venture and West Epsilon. The collected data will be from 2004 until the end of 2010, but data prior to 2010 will not be as detailed as the data from 2010. Detailed information on the management of failures will therefore mainly be from 2010.

Only the economic consequences will be taken into consideration, ignoring all other consequences such as personnel injury, environmental disasters and so on.

Interview with onshore and offshore maintenance personnel will be conducted in order to complement the data analysis.

1.3 North Atlantic Drilling Limited

NADL consists of five operating rigs and one rig under construction as of 3. April 2011 (Seadrill, 2011a).

North Atlantic Drilling Limited (NADL) was formed in April 2011, until then all the rigs now owned and managed by NADL was owned and managed by Seadrill Limited. Seadrill Limited was established in 2005 and has since been in rapid expansion, going from a total of 21 operating units when they acquired Smedvig ASA in 2006 to a total of 53 units operating as of February 2011 (Seadrill, 2011b).

2. Drilling units and equipment

We will here briefly introduce the drilling units used in theses thesis, their equipment and how a typical drilling operation is done.

2.1 Drilling Units

This study looks into NADLs five drilling units operating in Europe. Most of the drilling rigs have their own specifications, the biggest differences is the design of the hull and if it is a ram rig or draw work rig. We will briefly introduce the different rigs here with a short description of their design and recent track record.

2.1.1 West Alpha

Figure 1: West Alpha (Seadrill, 2011b)

West Alpha was built in 1986 and is the oldest of the drilling rigs, it have been modified several times during its lifetime, latest in 2009. It is a semisubmersible rig with draw works able to operate at water depths from 60 to 600 m with a drilling depth of 7000 m.

West Alpha has mainly been operating in the North Sea and during 2010 it operated in six different fields as shown in
Table 1. Prior to 2010 it has been operating in the North Sea since it was built, with only two operations in other areas.

Table 1: West Alpha track record 2010

Country	Operator	Field	Well Type	Well Start
Norway	Petro Canada	Statfjord Beta	Appraisal	July 2010
Norway	Statoil	Alve	Development sub sea completion	June 2010
Norway	Centrica	Cearus	Exploration	May 2010

Norway	Centrica	Fogelberg	Exploration	May 2010
Norway	Nexen	Brand	Exploration	January 2010

2.1.2 West Epsilon

Figure 2: West Epsilon (Seadrill, 2011b)

West Epsilon was built in 1993, but has been modified several times, latest in 2002. It is a Jack-up design with draw work able to operate on water depths up to 120 m with a drilling depth up to 9100 m.

West Epsilon has mainly been operating in the North Sea and during 2010 it only operated in one field as shown in Table 2. Prior to 2010 it has been operating in the North Sea since it was built, with only one operation in other areas.

Table 2: West Epsilon track record 2010

Country	Operator	Field	Well Type	Well Start
Norway	Statoil	Sleipner 15/9-B	Development/Exploration wells	July 2009 - present

2.1.3 West Venture

Figure 3: West Venture (Seadrill, 2011b)

West Venture was built in 2000 at the Hitachi yard and is a semisubermsible ram rig able to operate at water depths up to 1800 m and with a drilling depth exceeding 9000 m.

West Venture has only been operating in the North Sea and during 2010 it operated on one field as shown in Table 3.

Table 3: West Venture track record 2010

Country	Operator	Field	Well Type	Well Start
Norway	Statoil	Troll 31/2	Development/P&A/Completion	March 2000 - present

2.1.4 West Phoenix

Figure 4: West Phoenix (Seadrill, 2011b)

West Phoenix was built in 2008 and is a submersible ram rig able to operate at water depths up to 3000 meters and with a drilling depth exceeding 9000 meter.

West Phoenix has only been operating in the North Sea and during 2010 it operated on three fields as shown in Table 4.

Table 4: West Phoenix track record 2010

Country	Operator	Field	Well Type	Well Start
UK	BP UK	Devenick 9/29a-S2	Development subsea completion / HPHT	December 2010
Faroe Island	ENI Denmark	Anne Marie 6004/8a-A	Exploration	July 2010

2.1.5 West Navigator

Figure 5: West Navigator (Seadrill, 2011b)

West Navigator was built in 2000 and is a dynamically positioned drill ship with a ram rig able to operate at water depths up to 2500 meters and with a drilling depth exceeding 9000 meters.

West Navigator has only been operating in the North Sea lately and during 2010 it operated on one fields as shown in Table 5. Prior to 2010 it have operated in several different areas since it was built.

Table 5: West Navigator track record 2010

Country	Operator	Field	Well Type	Well Start
Norway	Shell	Ormen Lange	Development drilling and subsea completion	September 2005

2.2 Drilling equipment

One of the main challenges for NADL is that few of the drilling units operating in Europe are of the same design. They have however tried to make a generic equipment hierarchy across the different designs, shown in Table 6. This is based on the SFI group system (Skipsforskningsinstitutt, 1983), but there are some variations in the coding from rig to rig.

Table 6: Equipment groups used by NADL, based on SFI

RIG		
Drilling Equipment and systems	Platform Equipment	Platform Common Systems
- Derrick With Components - Drill Floor Equipment and Systems - Bulk and Mud Systems - Well Control Equipment and Systems - Pipe Handling Equipment and Systems - Drill String and Downhole Equipment and Systems - Material Handling Equipment and Systems - Service Equipment and Systems - Misc. Equipment, Systems and Services	- Maneuvering Machinery and Equipment - Navigation and Searching Equipment - Communication Equipment - Anchoring, Mooring and Towing Equipment - Repair, Maintenance and Cleaning, Outfitting - Lifting and Transport Equipment for Machinery	- Ballast and Bilge Systems. Gutter Pipes Outside - Fire & Lifeboat alarm, Fire Fight & Wash Down. - Air And Sounding Systems from Tanks to Deck - Special Common Hydraulic Oil Systems - Electrical Power Supply - Electrical Distribution Common Systems - Electrical Common Systems - Electrical Consumers

The equipment groups in Table 6 is used for further analysis in this thesis and the most relevant groups will be further explained.

Each of the different groups in Table 6 have a designated number, for instance all equipment under the “Drill Floor Equipment and Systems” have an object id starting with 31. Under this group we find the “Rotary table, top drive and associated equipment” with object id 313. For the rigs that don’t follow this coding structure we have still sorted the equipment under these codes, but have had to do it manually.

Within these groups there is some equipment that has to be in working condition in order for the rig to function as intended. The equipment needed for the rig to function as intended depends on what the rigs operation is at the time. Moving the rig will require a different set of equipment than drilling for instance. The equipment in these sets are what we define as critical equipment, this means that they are all critical in order for the rig to perform as intended.

Since the main purpose of the rigs in this study is drilling operations we will focus on the equipment critical for such operations. If one or more of the critical equipment fails the entire drilling operation will fail and we will experience downtime.

A drilling operation has four main operations; rotating, hoisting, circulating and power. Each of these four main operations requires different sets of equipment. We will briefly explain the four main operations and mention some of the equipment used.

In order to drill a hole you need to rotate a drill bit, this is normally done by rotating the entire drill string with the use of a turntable or hydraulic powered top head drive. Figure 6 is a simplified illustration of the equipment used in a typical drilling operation. Here you can see the turntable and the engines that turn it.

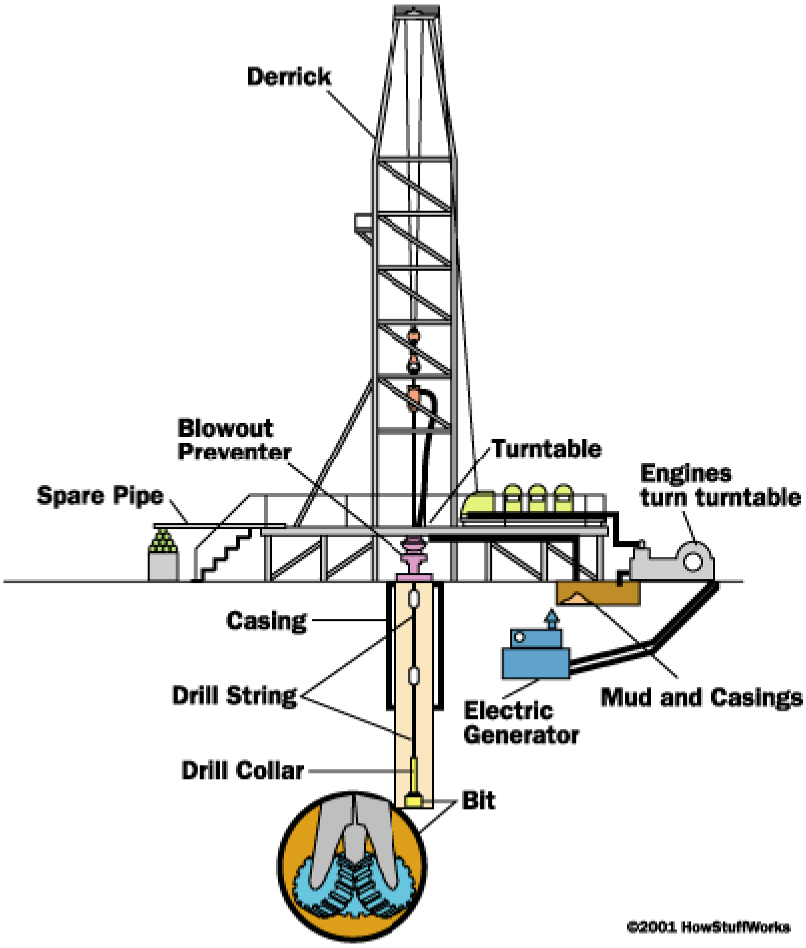

Figure 6: Anatomy of an oil rig (www.howstuffworks.com, 2011)

When you have drilled a certain distance you need to attach a new pipe to the drill string. In order to do this you need to hoist the pipe before connecting the new pipe to the drill string. This is done either by the use of draw works or a hoisting ram; in Figure 6 we have a derrick with draw works. The main difference between this setup and a ram rig using a hoisting ram is that the hoisting ram, as seen in Figure 7, uses hydraulic rams to hoist and lower the pipes in cooperation with the hoisting lines.

Figure 7: Ram rig (www.ogj.com, 2011)

The circulating system has several important functions;

- Transport rock fragments and cuttings from the bottom hole to the surface
- Reduce friction for the drill bit
- Cool the drill bit
- Maintain pressure in the hole and prevent the surrounding formation to enter the hole.

A drilling fluid, called drilling mud, is used for this. The mud is normally a mix of water, minerals, clay and chemicals that are mixed in tanks on the platform and circulated down the drill string, out of the drill bit and back to the platform through the annulus as shown in Figure 8.

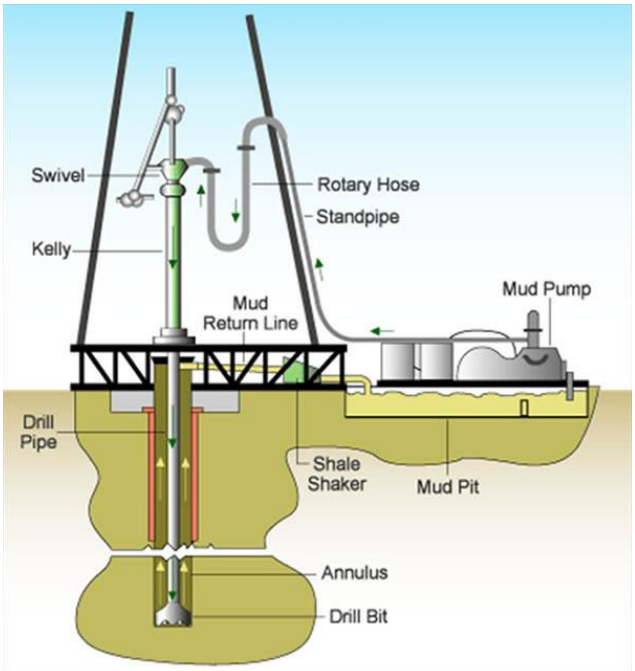

Figure 8: Mud circulating system (www.petroleumonline.com, 2011)

For the different equipment to work we need power. Normally we use one or more generators that provide electricity for this.

In addition to the equipment needed in order to perform the four operations mentioned above we have to have some safety barriers in place in case we lose control of the well. The most important safety barrier is the blowout preventer (BOP) as you can see in Figure 9. The BOP is in essence a large valve that the drill string is routed through, the main functions of this valve is to stop uncontrolled flow and pressure from the well from reaching the platform. The BOP does this by sealing of the well and its fluids, preventing it from reaching the platform. Losing control of the well can have very serious consequences, not only economically, but also for the environment and the safety of the personnel. The Deepwater Horizon accident is a good example of the possible consequences of a failure in the BOP (DNV, 2011b). Because of the possible severe consequences of a failure there are very strict rules and regulations when it comes to BOP`s, and you are not allowed to continue drilling if the BOP don't fulfill these requirements.

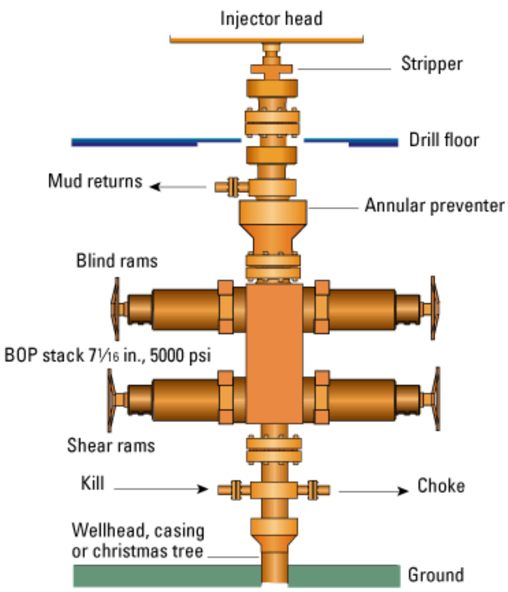

Figure 9: Diagram of blowout preventer (www.slb.com, 2011).

2.2.1 Differences from rig to rig

As we briefly have shown in chapter 2 there are some differences in drilling equipment from rig to rig. The main differences are caused by the rig either being a draw work rig or a ram rig. Except for this difference there are mostly only minor differences in the equipment relating to having different manufacturers. A short overview of the differences in manufacturer of some of the equipment on the rigs in this study is shown in Table 7.

Table 7: Manufacturers of equipment on the different rigs

	West Alpha	West Phoenix	West Navigator	West Epsilon	West Venture
BOP	Cameron T BOP 18 ¾” – 15k	Cameron 18 ¾”	Hydril, Compact BOP 18 ¾” – 15k	Cameron 21 ¼” – 5k, Shaeffer 13 5/8” 15k	Hydril, Compact BOP 18 ¾” – 15k
BOP Control System	Cameron, Pilot hydraulic system – 3000 psi WP	Cameron	Hydril, Multiplex	Koomey	Hydril, Multiplex
Topdrive	MH DDM 650-C-DC-500 S	DDM 650 HY Aux rig DDM 1000 HY Main rig	Main rig MH 750 t Aux rig 650 t Hydraulic Units	Varco TDS	2 ea DDM 650 HY
Rotary Table	Wirth RTSS 49.5” Hydraulic Driven	Wirth 60 1/2" Wirth 49 1/2"	2 ea Varco RST 60 1/2"	CET-4950-65 Hydraulic Driven	2 ea Varco RST 60 1/2"
Drawworks / Ram Rig	Wirth GH 3000 E	Aker MH, hydraulic with 4 cylinders (RAM)	Aker MH, hydraulic with 2 cylinders (RAM)	CE C3 3000 HP	Aker MH, hydraulic with 2 cylinders (RAM)

The small differences in equipment from one rig to another can, in some cases, make it difficult to transfer lessons learned from one rig to another. In order for the experience and knowledge to be relevant the equipment has to be identical. The differences in the equipment caused by having different manufacturers can cause differences when operating and maintaining the same type of equipment from rig to rig.

An advantage with these differences is the possibility to compare different manufacturers with regards to reliability and maintenance demands. For future builds and modifications this information can be used when selecting manufacturer of the different equipment.

3. Methodology

In this study we have primarily used two different analysis methods. The main contribution to our data has been the different databases made available by NADL. Reports have been generated with the help of these databases and exported into excel or manually read for further analysis. In excel we have primarily used quantitative analysis techniques, by counting the amount of reports that fulfill certain, selected, requirements.

To select the equipment groups used in this study we have done a quantitative analysis to see what equipment groups that are main contributors to downtime. We have also done a Pareto analysis in order to confirm our choice of equipment groups. The Pareto principle states that 20% of the sources cause 80% of the problems (Pareto, 1896).

Quantitative analysis has also been used to detect trends and to do most of the analyses based on data collected from the internal databases.

In addition to the quantitative analysis we have also done a series of qualitative analyses. Here we have opened, read, interpreted and checked the reports for inconsistencies and crosschecked vital data against other available databases.

To better understand the results we got from our analysis's we did a series of interviews with both offshore and onshore personnel. The interviews were also used in order to find possible ways to improve the maintenance management. We also conferred and discussed our results with technical personnel and management while performing our analyses.

4. Data analysis and discussion

In this chapter we will first present and briefly explain the different reporting tools and databases investigated in this thesis, then we will present our analysis`s and discuss the results of these.

4.1 Reporting tools and databases

Within the NADL organization they use several databases, each with their own main functions. For work orders and downtime reporting there are mainly three databases used, IFS, DODA and Synergi. Each of these databases uses unique reports and has different main purposes; they have been used for different reasons in this thesis, supplementing each other.

4.1.1 IFS

NADL uses IFS (www.ifsworld.com, 2011) for maintenance, procurement and logistics. In this study we have been looking at the maintenance part of IFS and especially the corrective maintenance reported in IFS.

When this paper was written IFS had two options when first creating a corrective action, to create a fault report or to create a work request as seen in Figure 10. A fault report is chosen when the user want to report a fault or suspected fault on equipment while a work request is chosen when the user want to report a job needing to be done without there being a fault. The mandatory information needed in the system is depending on what option the user chooses.

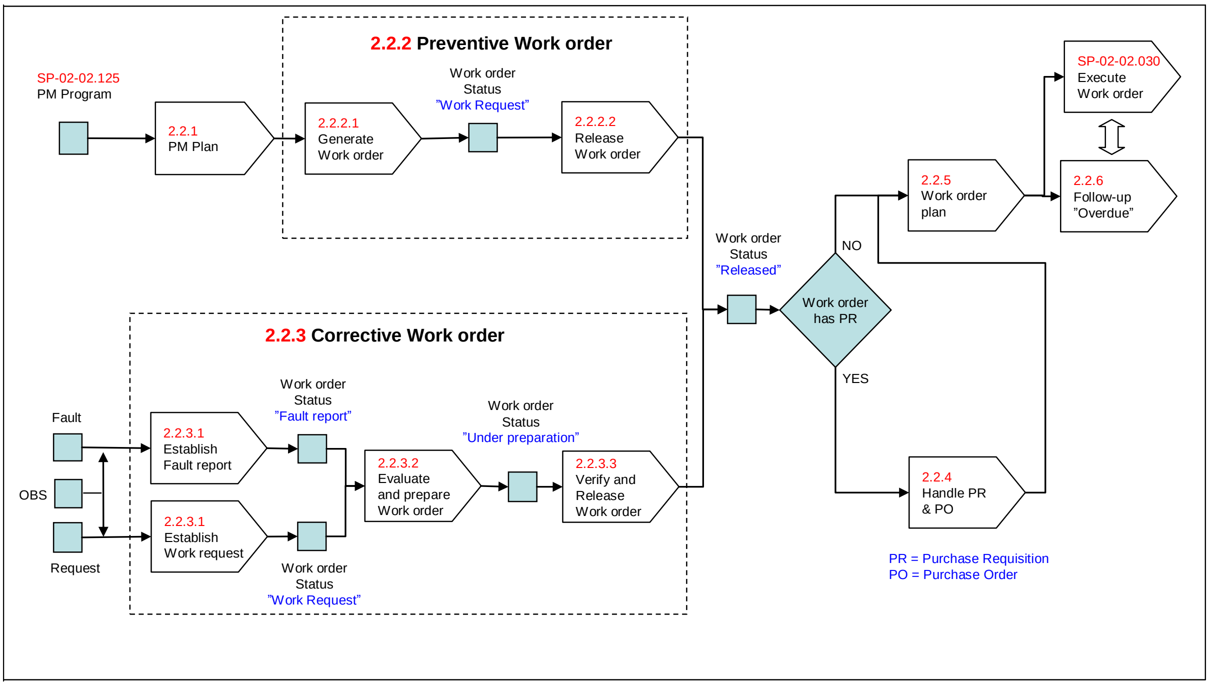

Figure 10: Workflow for creating and planning of WO`s in IFS (Seadrill, 2011d)

When filling out a fault report the user have to fill out the following fields:
- **Date**: The current date when the report is filled out.
- **Site**: What rig the fault report is for.
- **Reported by**: Who is making the report.
- **Maintenance Organization**: Which department that should perform the work.
- **Object ID**: The unique Object ID for the equipment that the fault report is made for.
- **Fault description**: A short, but concise, description of the fault.
- **Priority**: The priority is determined by use of Table 8.

Table 8: Decision criteria's for choice of priority when reporting CM in IFS (Seadrill, 2011d)

Priority	Health, safety and environment	Material damage	Operation
1	• Potential for serious damage • Safety-critical system out of service • Potential for fire in classified area • Potential for major emission/discharge to external environment	• Considerable material damage >1 mill. NOK	• Longer stop in operations
2	• Potential for injury requiring medical treatment • Limited impact on safety systems • No risk of fire in classified areas • Moderate potential risk of emission/discharge to external environment	• Moderate material damage >100,000 <1 mill. NOK	• Shorter stop in operations
3 & 4	• No potential for injury • No impact on safety systems • No risk of fire • No potential risk of emission/discharge to external environment	• Negligible material damage <100,000 NOK	• No stop in operations

When filling out a work request the user have to fill out the following fields:
- **Directive**: Short description of the error
- **Maintenance organization**: Which department that should perform the work
- **Reported by**: Who is making the report

There are in general few mandatory fields in IFS and the mandatory fields do not guarantee the quality of the filled in information. The mandatory fields in IFS only demands the user has to make some sort of input before he or she is allowed to save the sheet in IFS. The purpose of the mandatory fields is not for IFS to ensure the quality of the input, but to remind the user of what fields he or she have to fill out according to the internal routines. This removes the risk that a user forgets to fill in certain required fields, but it does however not remove the risk that the user might fill in poor/bad information. The user can write anything he or she wants in to the field and IFS will accept it; even a blank space will be accepted.

4.1.2 DODA

DODA which stands for Daily Operations Database Application have been in use by NADL (previously Seadrill and Smedvig) since 2001. In DODA the different rigs report in vital data and comments regarding the day to day operation of the rig. The information reported in DODA is:

- **Well (Rig and Well):** Information about installation, operator and well identification
- **AFE**: Information regarding the well time budget
- **Technical Limit**: Information about technically feasible AFE for the well
- **Section**: Here data are entered about the well's sections (depth etc.)
- **Daily Drill**: Daily input of drilling and well data
- **Operations 24h**: Daily input of drilling and well data
- **Drill Parameters**: Daily input of operational data
- **Daily Marine**: Daily input of marine data
- **Misc. Marine**: Daily input of marine data
- **Helicopter Traffic**: Daily helicopter traffic
- **Boat Movement**: Daily vessel traffic
- **Bit**: Information about drill bits
- **Week**: Weekly input of operational information

In this study we have mainly used DODA for its downtime reporting. All downtime for the different rigs are reported in DODA, regardless of the reason. It is divided into two main categories or codes, code 7 and code 8. All downtime that is planned and agreed upon with the contractor is reported as code 7, while all unplanned downtime is reported as code 8.

The requirements and possibilities to use code 7 will depend on the contractual agreements between NADL and the contractor. There is normally a maximum amount of hours each month where the rig can have planned downtime without losing income. The time and length of the downtime must be reported to and agreed upon with the contractor a certain time prior to the downtime is to begin, typically at least 48 hours.

4.1.3 Synergi

Synergi has been in use by NADL for a number of years, but it has only been in use as a downtime reporting tool since February 2010. It is a risk management system aimed at increasing the HSEQ performance of the organization and to reduce related costs.
The main purpose of Synergi within NADL is HSEQ reporting and tracking.

Since we only are concerned with failures related to maintenance we will limit our use of Synergi to the reporting of incidents leading to downtime.

The different rigs deliver detailed reports on every downtime incident daily, no later than the following day at 07:00hrs local time (Seadrill, 2011e).

Each report shall contain (Seadrill, 2011e):

- **Equipment references**: The equipment which is not functional and prevents operational performance must be specified.

- **Economic loss**: The economic loss must be indicated as the "worst case", meaning "day rate x days involved". Unused repair hours credited shall not be taken into consideration in this respect.

- **Root Cause Analysis**: The underlying root cause(s) for the incident shall be identified and reported.

- **Lessons Learned**: Whenever a downtime incident takes place, it must be evaluated whether lessons learned can be transferred to other units. In order to ensure the experience transfer, the appropriate action for the other units in question must be outlined in the respective downtime report.

The lessons learned transfer follows the guidelines presented in Figure 11.

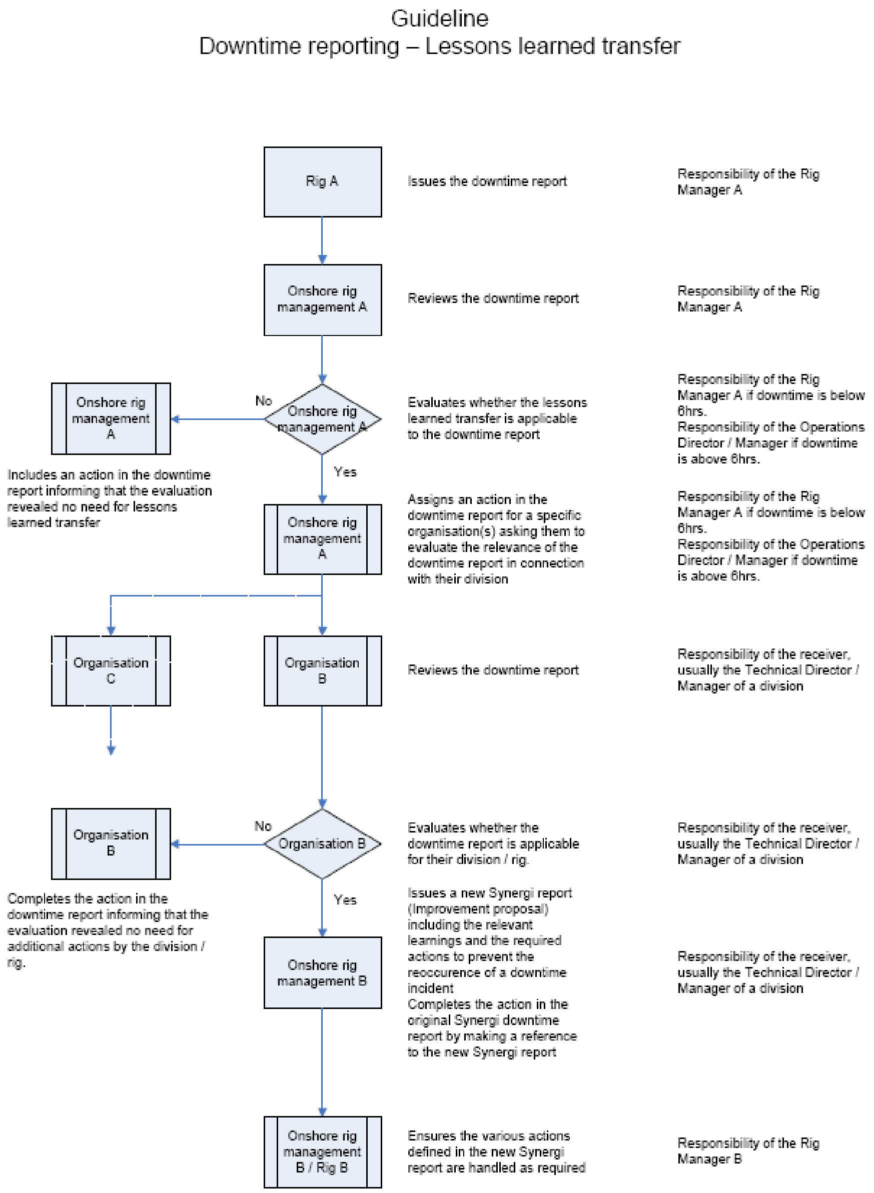

Figure 11: Guideline for lessons learned transfer in Synergi (Seadrill, 2011c)

4.2 Downtime

In this paper we define downtime as any period of time where the rig is unable to follow its planned operation due to equipment and/or personnel failure.

Optimizing the performance of an operation is always of great interest for a company. The balance between the increase in cost of maintenance and the loss of income due to downtime is often difficult to determine and is subject to many studies (Sattler and Reed, 2004, Khelifi, 1999, Dew and Childers, 1989, Chapman and Brown, 2009, Ogidan and Coetzer, 1993, Wolter et al., 2006).

In order to best estimate the maintenance optimization of equipment we need to look at the consequences of the failures, the possibility of the failures and root causes. This can be done with techniques such as FMECA (Military, 1984). An analysis of the equipment is normally done in order to determine the best suited maintenance program. This program is then modified as new knowledge is gathered during the lifetime of the equipment and/or similar equipment. These modifications of the maintenance program are done with the purpose of improving the balance between performance, maintenance and cost. Since the modifications rely on historical data it is important that the data collected over the lifetime of the equipment is managed and reported in the best way possible. The better the data is managed and reported the more likely we are to find the optimal balance between performance, reliability and cost.

Since the use of reported data is essential in the making/modification of a maintenance program it is important that it is of good quality, covering the correct equipment groups and over as long time as possible. This is off course not possible to achieve the first time a system is used, but during the lifetime of the system such reports will most likely contribute to improved maintenance programs and cost savings for the company.

4.2.1 Main contributors to downtime

In order to find the equipment groups that causes the most downtime we have gathered data from Synergi and divided the different equipment on the MODU`s into groups, as described in chapter 3. By doing a quantitative analysis of the gathered data we found 15 groups that, combined, caused 94% of the downtime from January until October 2010. The contribution from each group is presented as percentage of total downtime in Table 9.

Table 9: Percentage of the total downtime in 2010 for the European rigs associated with different equipment groups

Equipment group	Percentage
Rotary table, top drive and associated equipment	24 %
Side thrusters	23 %
Riser system incl. choke, kill and booster lines	16 %
Blowout preventer control system	12 %
Miscellaneous equipment for pipe/tubular handling	4 %
Drill floor tubular handling equipment	3 %
Drawworks & Machinery	2 %
Derrick mounted vertical pipe handling system	2 %
Windlasses with chain stoppers, rollers, etc	2 %

Mud Supply	1 %
Travelling equipment	1 %
Drilling control	1 %
Tensioning system	1 %
Overhead cranes	1 %
Choke and kill system incl. mud/gas separator	1 %
Total	94 %

Here we observe that side thrusters caused 23% of the downtime, after consulting with qualified personnel we found this to be an unexpected high percentage. A closer look at the collected data reveals that one rig, West Navigator, had significant and uncharacteristic problems with the side thrusters in 2010. Over a longer period of time the side thrusters will most likely be the cause of a far lower percentage of the total downtime. As further analysis will show the root cause for the downtime caused by the side thrusters are not maintenance related, but design related, and we will therefore not go further into this discussion.

Figure 12 and Figure 13 includes all groups having caused downtime in 2010 and show how many percent of the total downtime the different equipment groups are responsible for and. This is based on data collected from MODU`s located in Europe and in the Eastern Hemisphere. We chose to include data from rigs located in the Eastern Hemisphere to better compensate for the short period of time the data covers.

By doing a Pareto analysis (Pareto, 1896) in Figure 13 we can see that the downtime contribution follows the Pareto principle with approximately 20% of the equipment groups contributing with 80% of the downtime. In theory one can eliminate 80% of the current downtime by avoiding downtime in five equipment groups.

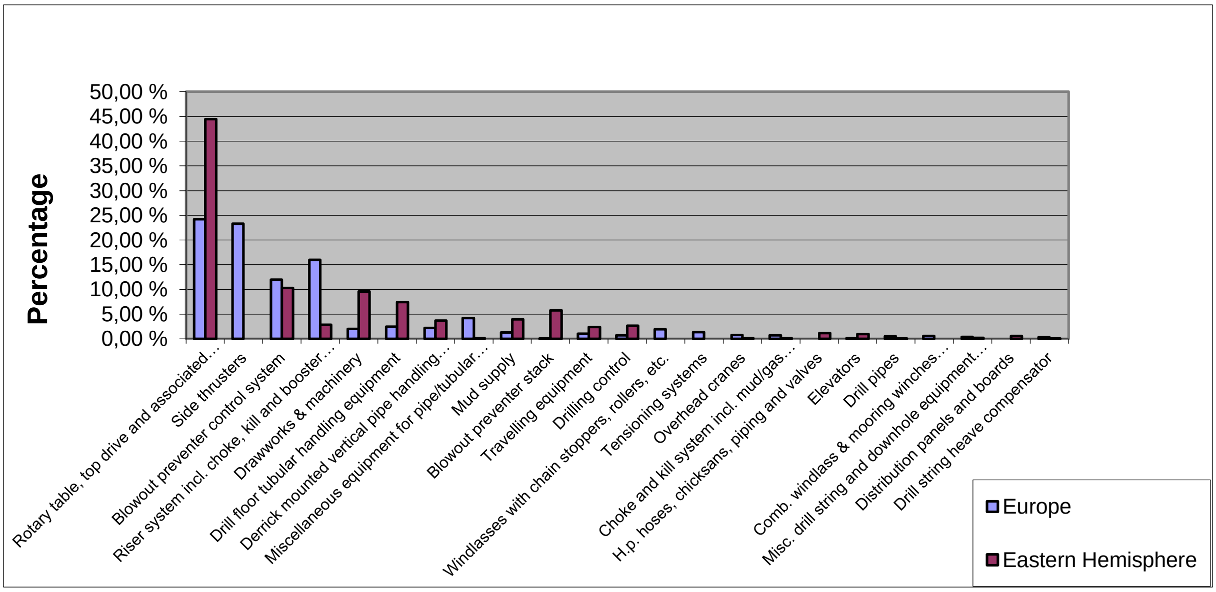

Figure 12: Downtime percentage of equipment groups Europe Vs Eastern Hemisphere 2010

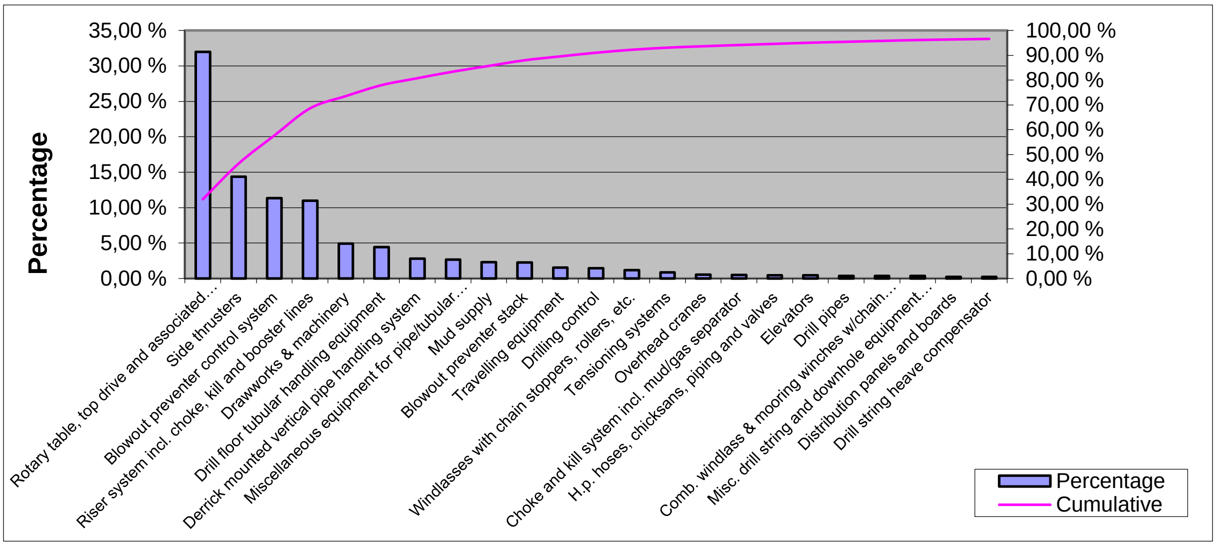

Figure 13: Pareto analysis of the average downtime for rigs in Europe and Eastern hemisphere 2010 by equipment groups

The cost of the downtime related to equipment groups, estimated as loss of income, is shown in Table 10. This table is based on data collected from the European rigs only.

Over a period of 10 months these selected 15 groups have been the cause of a combined loss off income due to downtime of almost 48 million US dollars. Here we clearly see that four groups have very high downtime costs compared to the rest of the groups. These four groups contribute with approximately 40 million US dollars in downtime cost alone, over 80% of the total downtime cost for the 15 groups. Since the cost is estimated as loss of income we get the same top groups here as if we look at the downtime hours for the European rigs in Figure 12.

Table 10: Loss of income due to downtime from January until October 2010

Equipment group	**Percentage**	**USD**
Rotary table, top drive and associated equipment	22%	10 420 776
Side thrusters	21%	10 157 656
Riser system incl. choke, kill and booster lines	26%	12 523 146
Blowout preventer control system	16%	7 605 893
Miscellaneous equipment for pipe/tubular handling	4%	1 915 437
Drill floor tubular handling equipment	2%	1 027 840
Drawworks & Machinery	~1%	646 466
Derrick mounted vertical pipe handling system	~1%	704 200
Windlasses with chain stoppers, rollers, etc	~1%	730 000
Mud Supply	~1%	696 850
Travelling equipment	~1%	214 500
Drilling control	~1%	236 375
Tensioning system	~1%	593 437
Overhead cranes	~1%	185 000
Choke and kill system incl. mud/gas separator	~1%	242 793
Total	100%	47 900 369

When further investigating the collected data on downtime during the last year we are able to find the root causes for the downtime. Table 11 shows how many percent of the total number of downtime events the different root causes are responsible for, Table 12 shows how much of the total estimated cost related to downtime the different root causes are responsible for. Since the downtime cost is directly related to the downtime hours we can use the downtime costs in Figure 18 as an estimator for the downtime hours.

Table 11: Root cause analysis of downtime events from January until October 2010

Root Cause	Events	Percentage
Poor Maintenance	99	**35,6**
Poor Design	51	**18,3**
Poor Quality	47	**16,9**
Error of Use	31	**11,2**
Procedure	12	**4,3**
Equipment Failure	8	**2,9**
Other	30	**10,8**

One can see that the root causes with the most events not necessarily contribute with the most downtime; there is no direct connection between high frequency and high cost.

Table 12: Root cause analysis of downtime cost from January until October 2010

Root Cause	USD	Percentage
Poor Quality	12 798 898	**26,6**
Poor Design	11 564 074	**24**
Equipment Failure	10 447 956	**21,7**
Error of Use	6 223 565	**12,9**
Poor Maintenance	4 837 774	**10,1**
Procedure	209 562	**0,4**
Other	2 023 960	**4,2**

We can see that poor maintenance is identified as the main root cause in 35% of the events leading to downtime. When we look at the cost of the related downtime, these events do however only count for 10% of the total costs. There might be a series of reasons for this, but when we look at the different root causes and their downtime, the most likely reason is that the repair time/downtime due to poor maintenance is less than for other groups. Further analyses of the downtime reveals this to be true as can be seen in Table 13. The difference in percentages from Table 12 and Table 13 is caused by the differences in day rates from contract to contract.

Table 13: Root cause analysis of downtime from January until October 2010

Root Cause	Hours	Percentage
Poor Quality	553,25	**27,3**
Poor Design	392,25	**19,4**
Equipment Failure	455,15	**22,5**
Error of Use	291,75	**14,4**
Poor Maintenance	219,5	**10,8**
Procedure	10	**0,5**
Other	102,25	**5,1**

Since this paper is about maintenance we are not interested in downtime that is not related to this. Further analysis of the downtime reports gives us Table 14, which shows us how many downtime events the different equipment groups have had that can be related to insufficient maintenance.

Table 14: Number of events causing downtime as a result of insufficient maintenance and by equipment group

	Insufficient Maintenance	Other
Rotary table, top drive and associated equipment	17	31
Side thrusters	0	1
Riser system incl. choke, kill and booster lines	4	13
Blowout preventer control system	1	5
Miscellaneous equipment for pipe/tubular handling	4	8
Drill floor tubular handling equipment	14	22
Drawworks & machinery	6	4
Derrick mounted vertical pipe handling system	15	23
Windlasses with chain stoppers, rollers, etc.	0	1
Mud supply	4	9
Travelling equipment	0	2
Drilling control	2	10
Tensioning systems	0	2
Overhead cranes	6	3
Choke and kill system incl. mud/gas separator	1	4

Some of the equipment groups have not experienced any downtime that can be related to insufficient maintenance and we will therefore exclude them from further analyses. Further studies will be done on the 11 equipment groups listed in Table 15.

Table 15: Our chosen 11 equipment groups for further studies and the related SFI group code

Equipment Group	SFI group code
Rotary table, top drive and associated equipment	313
Riser system incl. choke, kill and booster lines	335
Blowout preventer control system	332
Miscellaneous equipment for pipe/tubular handling	347
Drill floor tubular handling equipment	342
Drawworks & machinery	312
Derrick mounted vertical pipe handling system	341
Mud supply	325
Drilling control	311
Overhead cranes	362
Choke and kill system incl. mud/gas separator	336

Looking at the reported costs for the downtime caused by these 11 groups in Synergi gives us Table 16. These reported costs in Synergi do however only take into consideration the loss of income due to the downtime and is calculated as described in chapter 4.1.3. It is however a good indication of the severities of a downtime event caused by the different equipment groups.

Based on these numbers we can see that the downtime events in the Rotary table, top drive and associated equipment group is the most expensive, with an average cost per event of 167 718 US dollars. The least expensive group is the Drawworks & machinery group, with an average cost per event of 9 630 US dollars, less than 6% of the most expensive group.
The total costs of downtime related to insufficient maintenance for all groups is 4 837 774 US dollars, our chosen 11 groups contributed with 4 397 372 US dollars, or 91%, of this.

Table 16: Cost of downtime related to insufficient maintenance sorted by equipment groups

	Total costs	Average cost per event
Rotary table, top drive and associated equipment	2 851 213 USD	167 718 USD
Riser system incl. choke, kill and booster lines	97 500 USD	24 375 USD
Blowout preventer control system	20 000 USD	20 000 USD
Miscellaneous equipment for pipe/tubular handling	78 000 USD	19 500 USD
Drill floor tubular handling equipment	363 187 USD	25 941 USD
Drawworks & machinery	57 781 USD	9 630 USD
Derrick mounted vertical pipe handling system	246 150 USD	16 410 USD
Mud supply	481 500 USD	120 375 USD
Drilling control	42 250 USD	21 125 USD
Overhead cranes	147 500 USD	24 583 USD
Choke and kill system incl. mud/gas separator	12 291 USD	12 291 USD
TOTAL	**4 397 372 USD**	59 423 USD

If we use Pareto Analysis (Pareto, 1896) to identify the important causes we get different outcomes depending on how we do our analysis. The Pareto analysis says that “80% of the problems are produced by 20% of the causes”. Accordingly, if we look at the number of events and ignore the cost we get Figure 14 where all equipment groups left of “Miscellaneous equipment for pipe/tubular handling” is considered important.

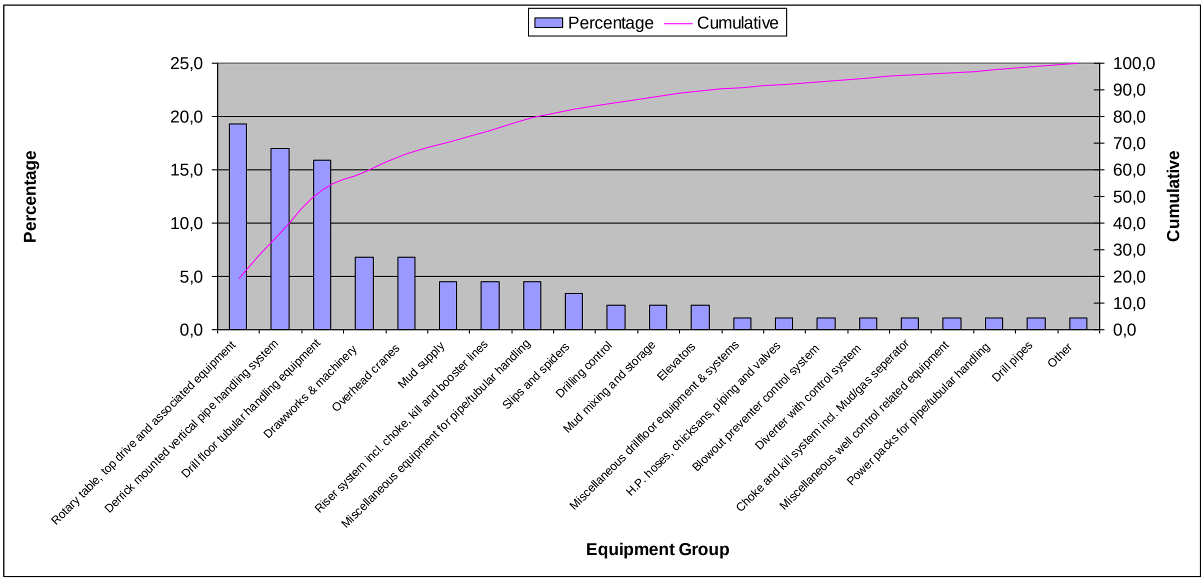

Figure 14: Pareto analysis of equipment groups causing failures, based on percentage of total events

If we look at the cost, and ignore the number of events, instead we get Figure 15, here fever equipment groups will be considered as important. Only 3 groups will here be considered as important, as opposed to 8 groups in Figure 14. We see that our main contributor, both in number of events and cost, is rotary table, top drive and associated equipment, contributing with almost 20% of the events and over 60% of the cost. This information is of importance when making adjustments to maintenance programs and focusing attention on the right equipment. Excluding equipment groups based on the Pareto analysis after already narrowing down our equipment groups by root cause and overall contribution to downtime will however not be done in this study. But this analysis clearly shows that improving the maintenance and reducing the downtime for the Rotary table, top drive and associated equipment group is most likely to reduce the overall downtime cost most of the groups studied.

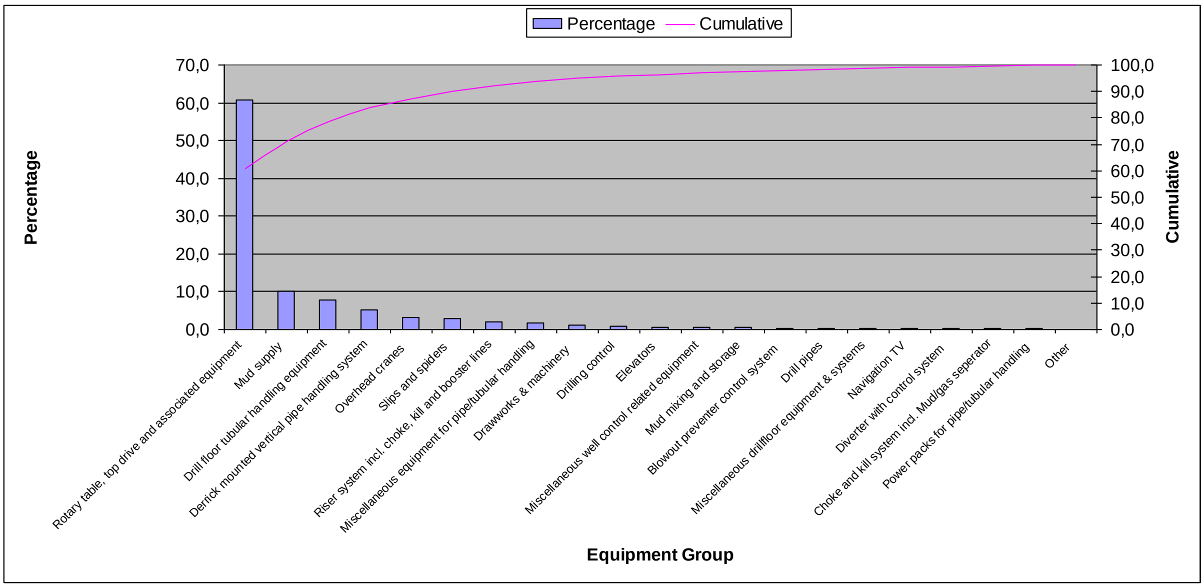

Figure 15: Pareto analysis of equipment groups causing failures, based on percentage of total cost

4.2.2 Downtime due to 3rd party suppliers

When looking at the total downtime of NADL`s rigs it can be of interest to know how much of the downtime that are caused by 3rd party suppliers. A good example is the problems West Navigator had in late 2009 and the beginning of 2010 with their thrusters. The thruster problems were the cause of 23% of the total downtime for the European rigs in 2010 as shown in Table 9. The reports identify the root cause of this event as poor design which the supplier was responsible for. While there might be no way of avoiding this kind of failures totally, it does highlight the importance of inspection and quality control of 3rd party suppliers and equipment.

Analyzing the reports from 2010 and identifying the downtime events where the root cause can be directly related to 3rd party supplier failures gives us Table 17. We can, for 2010, see that the 3rd party suppliers are causing 68% of the total downtime for the European rigs. One can however argue that this numbers are uncharacteristically high due to the short time span and the problems West Navigator had in January. If we, for argument sake, ignore January and only take into consideration the downtime between February and October we find that the 3rd party suppliers were the cause of 378 of a total of 962 downtime hours. That is the equivalent of almost 40% and clearly shows that the failures from 3rd party suppliers cannot be ignored when trying to reduce the total downtime.

The failures caused by 3rd party suppliers are typically poor design and/or poor quality and are difficult, if not impossible, to avoid with maintenance after installation. To reduce this downtime, preventive measures can be taken, such as increased inspection and control of both delivered equipment and manufacturers.

The downtime due to 3rd party suppliers is higher than the downtime directly related to poor or insufficient maintenance and, in our opinion, more difficult to reduce. The main reason is that maintenance is something the organization can monitor and improve continuously internally while design and quality problems must be detected by inspection prior to installation.

These figures does however indicate that the downtime due to 3rd party suppliers is something NADL should look closer at, perhaps increase their focus and resources used on inspection and control of purchased equipment and services.

Table 17: Downtime of the European rigs sorted by month and responsible part

	NADL	3rd Party	Total
January 2010	3,5	877,4	**880,9**
February 2010	3	18,25	**21,25**
March 2010	18	27,25	**45,25**
April 2010	14,25	51,5	**65,75**
May 2010	6,75	14,25	**21**
June 2010	200,25	113,25	**313,5**
July 2010	76,5	84,5	**161**
August 2010	10,75	17	**27,75**
September 2010	21	28,5	**49,5**
October 2010	233,75	23,5	**257,25**
Total	**587,75**	**1255,4**	**1843,15**

4.2.3 Trends in downtime

Average downtime in 2010 was 1 hour and 15 minutes per rig each day for NADL in Europe, approximately 5% downtime and 95% uptime. The numbers are similar for the eastern hemisphere in 2010. The downtime for 2010 does not take into account November and December and is very much influenced by West Navigators side thruster problem during the year in Europe.

Before 2010 there have not been any good systems within NADL to look at the causes of downtime. The downtime have been tracked by the use of DODA and to some extent IFS.

By gathering and analyzing the number of IFS reports that are marked as causing downtime we get Figure 16. From this figure one can see that there has been a decrease in downtime events since 2006 according to IFS. One of the reasons for this reduction might be the increase in experience with the different equipment. This is likely to improve maintenance and thereby reduce the number of events reported in IFS causing downtime. Other possible reasons are discussed in Chapter 6.

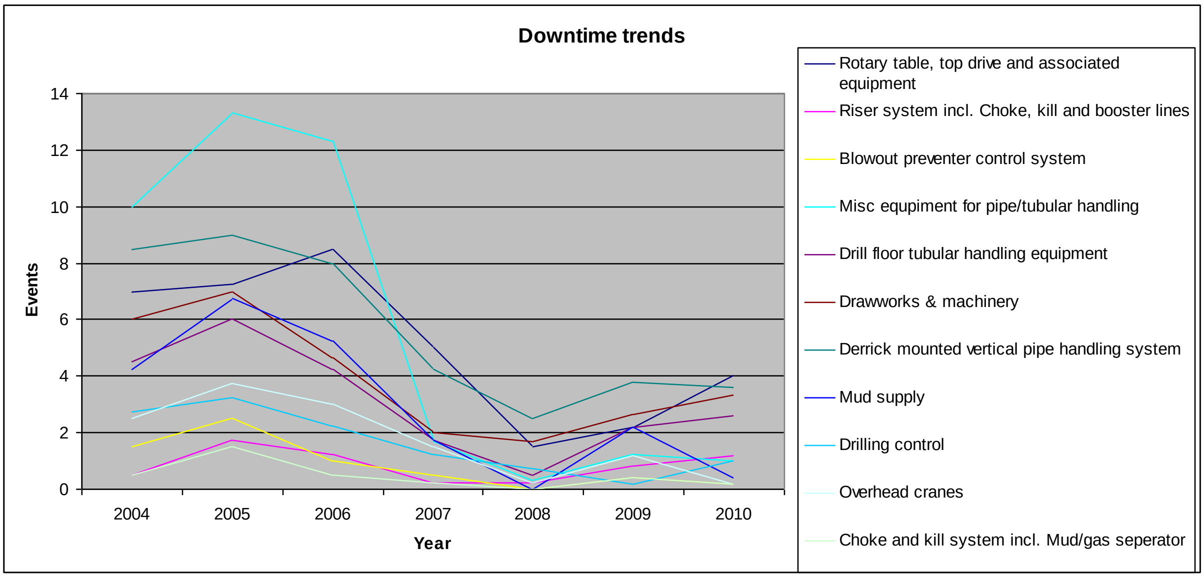

Figure 16: Average reported downtime events in IFS per rig per year sorted by equipment group

When we look at the yearly downtime since 2005 we can see that most rigs have a decreasing trend. As we can see from figure Figure 17; West Alpha, West Venture and West Epsilon all operate with a yearly downtime in the region between 0 and 800 hours/year, with an average below 500 hours/year. West Navigator is the main contributor to downtime most of the years and had an increasing downtime trend from 2005 to 2008, in 2009 there were a significant decrease in the downtime, but the downtime more than doubled again in 2010. In 2008 West Navigator had around ten times as many downtime hours as West Alpha and West Epsilon. The downtime caused by West Navigator is so much higher on average than the rest of the rigs that we when we look at the average downtime for all rigs from 2005 until 2010 the curve shape follow West Navigators downtime trends as seen in Figure 18.

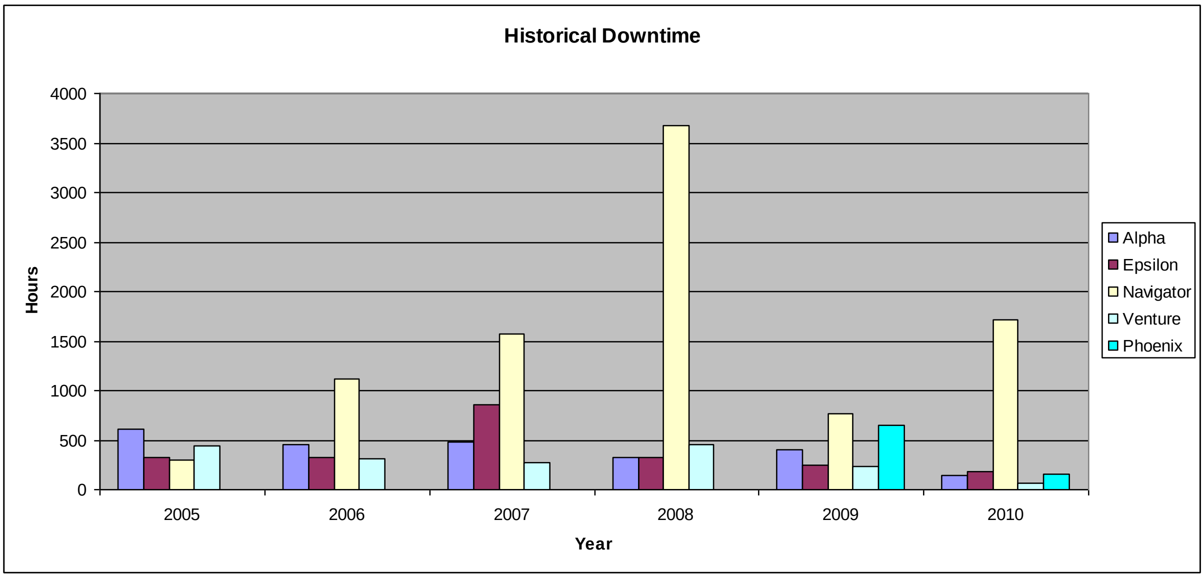

Figure 17: Historical downtime for the European rigs

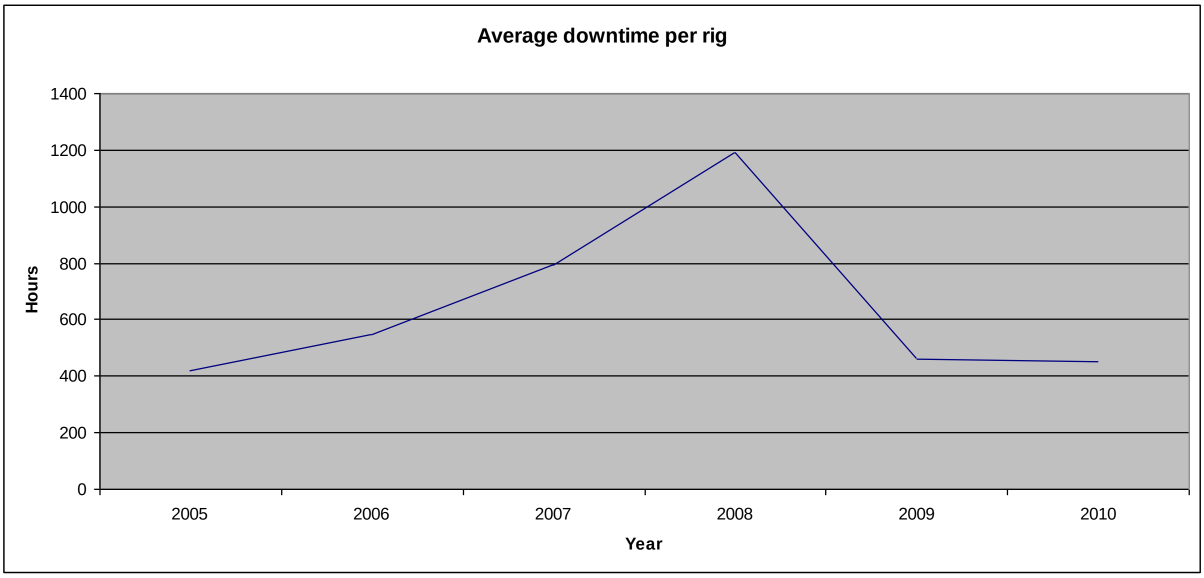

Figure 18: Historical average downtime per rig for NADL`s European rigs

Comparing the downtime hours reported in DODA with the number of downtime events reported in IFS we can find no obvious relation. While there is a significant decrease in the number of downtime events reported from 2006 to 2007, there is an increase in downtime in the same period. If we choose to ignore the downtime contributed by West Navigator we do however see a slight reduction in the average downtime from 2005 until 2010.

It can seem like NADL have successfully managed to reduce the downtime events causing little downtime, reducing the total number of events without reducing the overall downtime hours to the same degree.

4.2.4 Planned vs. unplanned downtime

There are two different types of downtime for NADL`s rig; planned and unplanned. There are certain criteria's that needs to be fulfilled in order for the downtime to be reported/categorized as planned. The two main criteria's are:

1. The contractor have to be notified a certain time prior to the downtime
2. The total planned downtime must be within an agreed upon limit between NADL and the contractor

The loss of income due to planned maintenance are subject to contractual agreements, but are always lower than for unplanned maintenance and can be non-existing.

Unplanned downtime is all the downtime that does not fulfill the planned downtime criteria's and will have more severe economic consequences. For such downtime there will be a loss of income estimated as the contractual day rate times the length of the downtime.

In DODA the downtime is reported as either code 7 or code 8, where code 7 is planned downtime and code 8 is unplanned downtime. Doing an analysis of the downtime reported in DODA since 2005 under code 7 and code 8 for the different rigs gives us Figure 19.

It is interesting to note that the rigs with the least planned maintenance also are the one with the most unplanned downtime. West Navigator has the most unplanned maintenance all years, except for 2005, and they have the least planned maintenance the same years.

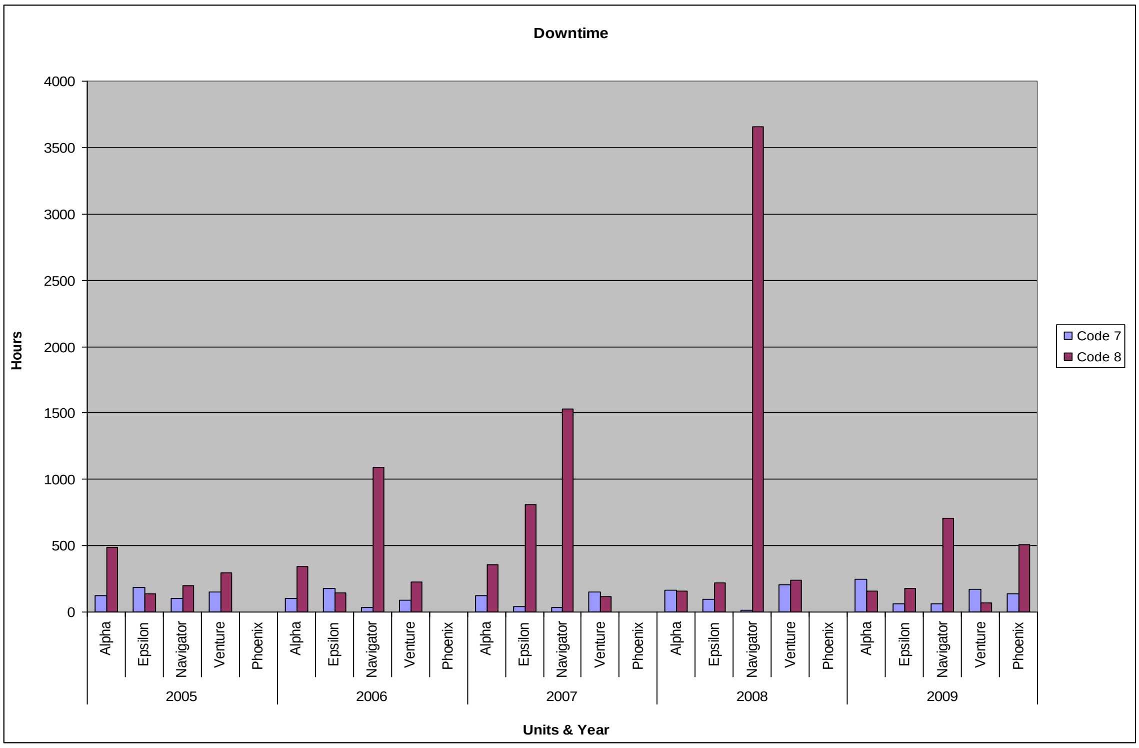

Figure 19: Historical unplanned (code 8) vs planned (code 7) downtime for the European rigs

We rarely see that there have been more planned than unplanned downtime, only in 6 out of 21 studied years this is the case. West Epsilon has had a decreasing trend in planned downtime while having a slightly increasing trend in unplanned downtime. The opposite is the case for West Venture and West Alpha, both having an increasing trend in planned downtime while reducing the unplanned maintenance. Since West Phoenix only has been in operation since the end of 2008 we do not have enough data to do any analysis of the trends over time for this rig.

When there is an increase in planned downtime there seems to be, on average, an even higher decrease in unplanned downtime. This can indicate that the planned downtime not only replace the unplanned downtime, but also reduces the overall downtime.

It is however important to remember that the criteria's for planned maintenance are subject to contractual agreements. The reported numbers alone will therefore not give a total and correct picture; it will only give us a rough idea of the trends over time and relations with the unplanned maintenance.

4.3 Non-critical failures

If we look at the reported corrective actions in IFS on our selected 11 equipment groups we get Figure 20. One can here see that there is a slight decrease in reported corrective actions in IFS starting from 2005 to 2006, after 2006 most groups seems to have a stable number of corrective actions each year. There are some similarities to the trend that we can see in Figure 16 which is the number of reported downtime actions reported in IFS. The decrease in reports is however not as clear and comes a little prior to the decrease in Figure 16.

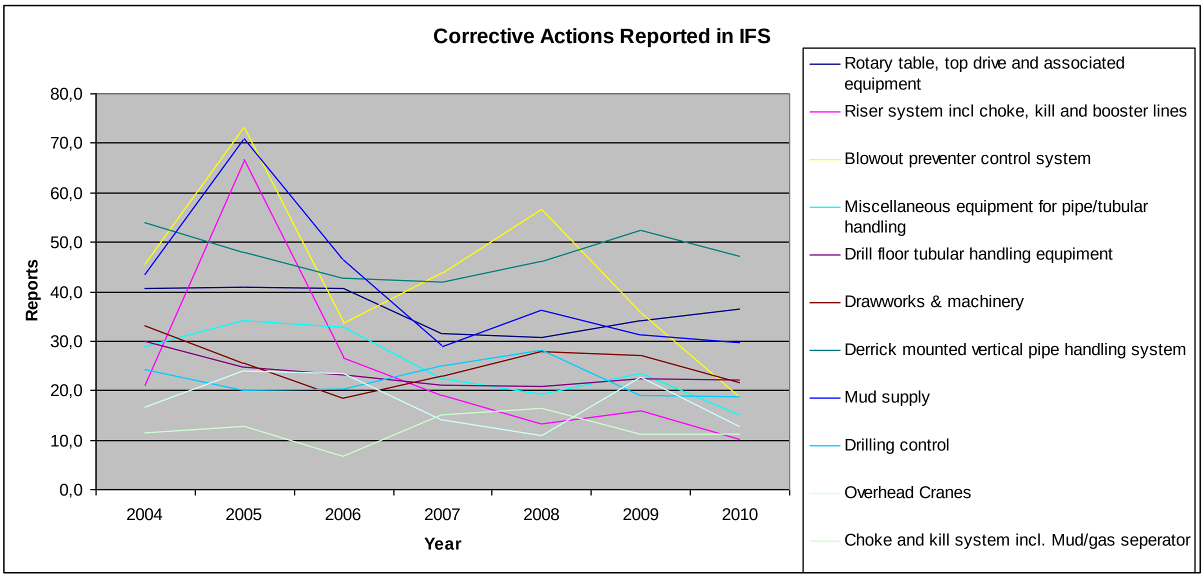

Figure 20: Average amount corrective actions reported in IFS per rig per year (Appendix A – Corrective Actions reported in IFS)

4.3.1 Failures that could be critical

By failures that could be critical we mean failures that would cause the rig to experience downtime if they had occurred in another phase of the operation. An example to illustrate this is if the rig already is unable to perform its intended operation and the rotary table experiences a failure. The failure in the rotary table is corrected before the initial cause of the downtime and therefore doesn't affect the experienced downtime. This failure would have been critical and caused downtime on its own if it had occurred during a drilling operation.

One way of possibly identifying these hidden downtime events are to look at the reported corrective actions in IFS during periods of downtime. Table 18 shows reported corrective actions in IFS during periods of downtime.

Table 18: Reported corrective actions in IFS during downtime

	IFS reports on days with registered downtime			
	Reported as downtime	Reported as no-downtime	Other	Total
Alpha	3	97	11	111
Navigator	62	393	10	465
Epsilon	10	203	1	214
Venture	0	143	13	156
Phoenix	13	179	33	225
Total	88	1015	68	1171

From this table we can see that there are a total of 1083 reported actions that possibly could have given downtime. Since the no-downtime reports in IFS don't contain any information regarding the potential consequences of the failure there is no easy way to find how many of these 1083 reported actions that could have this potential. To identify the actions with such a potential one have to manually read every report and interpret the information, which in most cases is insufficient. When studying the reports further in this thesis we found that the information given in each report was insufficient in order for us to make any conclusion on the potential of the failure. We can only note that there is a high amount of reported corrective actions on the days that have registered downtime and that some of this might have led to downtime.

If one are to study this further the company need to involve key technical personnel with the knowledge needed to interpret the IFS reports. But, even with the right knowledge, the lack of information in the reports will make it hard, if not impossible, to make such a study of quality.

4.3.2 Discussion of potential consequences

It is, in our opinion, very important to identify not only the occurred consequences of the failure, but also the potential consequences. The same failure can be critical in one phase of the operation and non-critical in another phase, despite the operation of the equipment itself being similar. Since the operation of the equipment is similar the failures that are classified as non-critical could just as well have been critical. By ignoring this potential consequence of the failure we get a wrong picture of the probability of downtime due to this failure. When setting up a maintenance program we balance between the cost and savings of the maintenance. It is therefore important that we get as correct as possible probabilities when we calculate the potential savings associated with the increase in maintenance. This is not only limited to the cost directly related to down-time, but also the indirect losses caused by loss in reputation and similar.

4.4 Planned Maintenance

When we look at the reported planned maintenance in IFS from 2004 until 2010 we get Figure 21. The yearly number of reports is here quite constant for each equipment group throughout the studied period of time.

There does not seem to be any connection between the number of corrective actions and planned maintenance reported in IFS. One amount of planned maintenance can have very different amount of corrective actions in the same period of time.

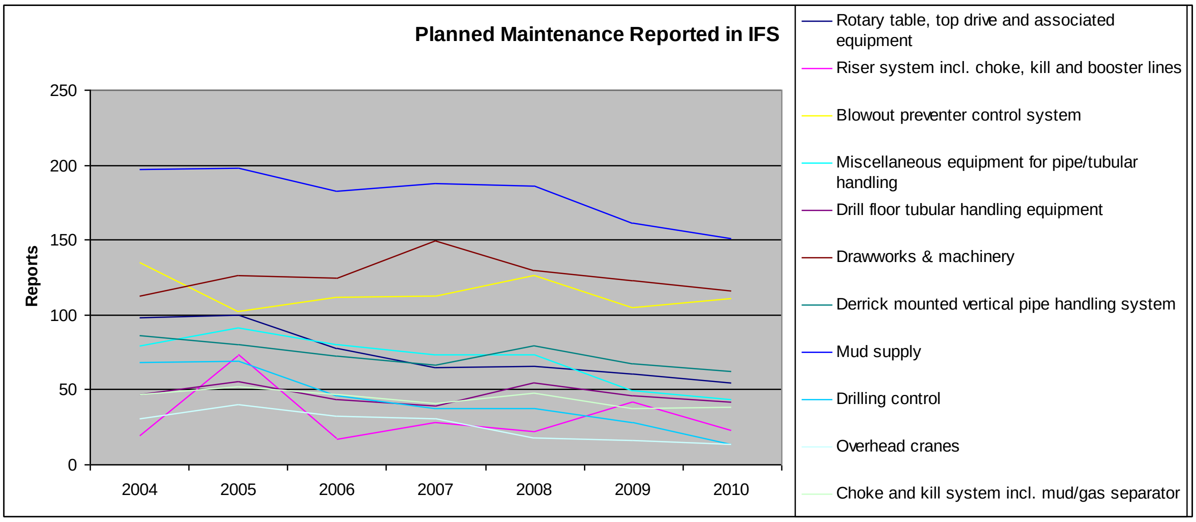

Figure 21: Average number of planned maintenance reported in IFS per rig per year

The planned maintenance does not seem to have affected the maintenance related downtime either. As shown previously there have been a decrease in maintenance related downtime, but we cannot see any decrease or increase in planned maintenance. The same applies for the number of downtime events reported in IFS where we could see a clear decreasing trend after 2006 in Figure 16, which cannot be related to any changes in Figure 21.

Based on these numbers there seem to have been little changes in the maintenance schedules for the rigs. It does not seem like the changes in downtime can be contributed to any changes in the frequency of the maintenance performed.

4.5 *Impact of major overhauls*

In order to look at the impact on downtime and failure frequency from major overhauls we have decided to look at two different rigs before and after their last major overhauls. The first rig we will look into is the West Alpha which had a major overhaul from 22.09.2009 until 24.10.2009. We will look at how the failure rate, spare part usage and downtime were before this overhaul and how it has been after.

The overhauls are normally done in connection with classification of the rig and the frequency is dictated by local laws and legislations. The rigs in our study follows DNV`s rules for offshore classification (DNV, 2011a) and the frequency dictated by it. The rigs in our case studies have been classed every 5th year. NADL is free to increase the frequency of these major overhauls, but they cannot decrease it and extend the period between the classifications.

4.5.1 West Alpha case study

Starting with the corrective actions reported the last year before last major overhaul we get Figure 22. In the same period the rig had a downtime as shown in Figure 23. The average downtime the last year before the overhaul was approximately 41 hours, and the average monthly reported actions are shown in Table 19.

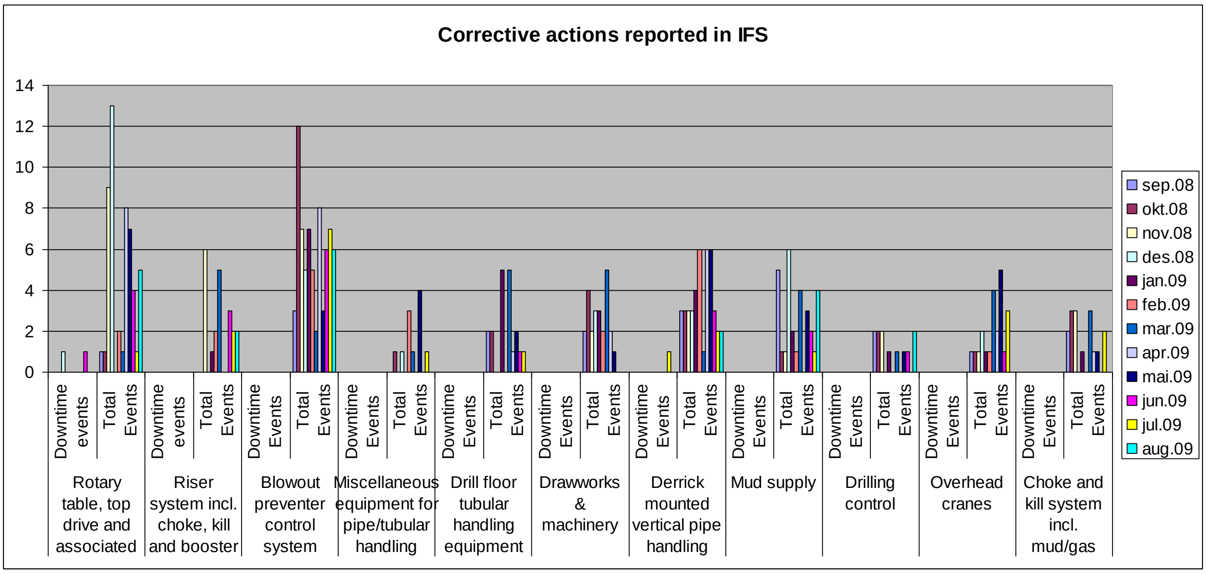

Figure 22: Number of corrective actions reported in IFS from September 2008 until last major overhaul in September 2009 for West Alpha

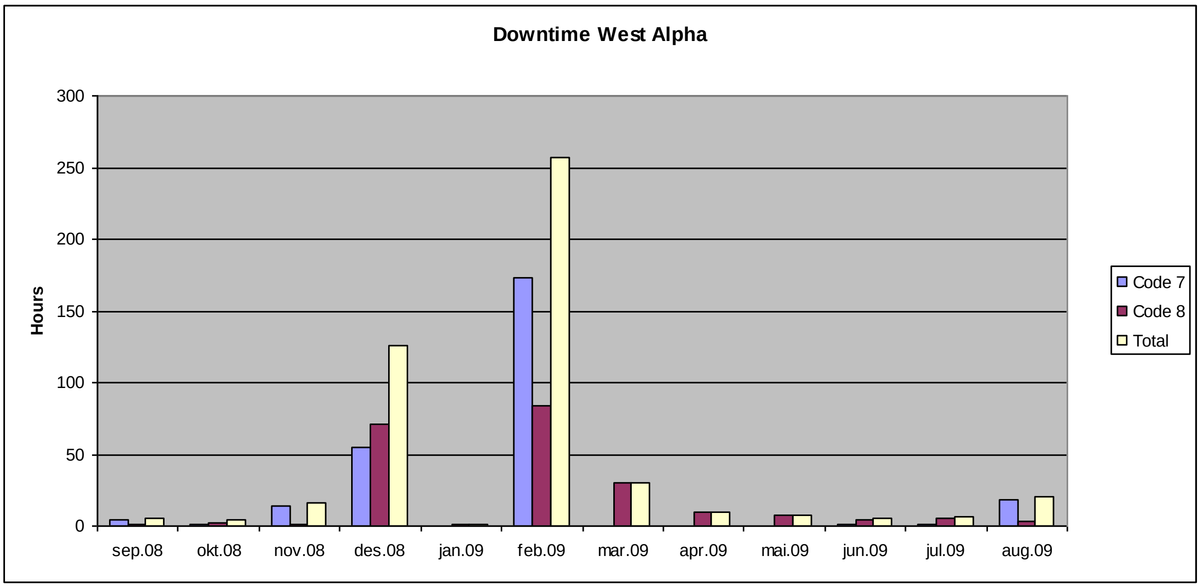

Figure 23: Downtime for West Alpha last year before last major overhaul

Table 19: Average monthly reported corrective actions for West Alpha from September 2008 until August 2009

Equipment group	Corrective actions
Rotary table, top drive and associated equipment	4,3
Riser system incl. choke, kill and booster lines	1,8
Blowout preventer control system	5,9
Miscellaneous equipment for pipe/tubular handling	0,9
Drill floor tubular handling equipment	1,6
Drawworks & machinery	2,0
Derrick mounted vertical pipe handling system	3,5
Mud supply	2,5
Drilling control	1,0
Overhead cranes	1,8
Choke and kill system incl. mud/gas separator	1,3
Total average	**2,4**

When we look at the first year after the last major overhaul we get a different picture. First we can look at the average monthly reported actions, shown in Table 20. The average monthly reported corrective actions have decreased from 2,4 prior to the major overhaul to 1,6 after the major overhaul. This is a 25% reduction and if we look into the different groups we can see a good decrease in the most critical equipment. The BOP system which is critical with regards to economics and HSE have a decrease in reported corrective actions from 5,9 to 2,7, which is the same as a 54% reduction.

Table 20: Average monthly reported corrective actions for West Alpha from November 2009 until October 2010

Equipment group	Corrective actions
Rotary table, top drive and associated equipment	3,3
Riser system incl. choke, kill and booster lines	1
Blowout preventer control system	2,7
Miscellaneous equipment for pipe/tubular handling	0,9

Drill floor tubular handling equipment	1,3
Drawworks & machinery	0,9
Derrick mounted vertical pipe handling system	2,6
Mud supply	2,6
Drilling control	0,8
Overhead cranes	0,6
Choke and kill system incl. mud/gas separator	1,4
Total average	**1,6**

There is however hard to find any obvious trends in the reported corrective actions month for month both before and after the overhaul. If we compare Figure 22 with the graph made with data collected after the overhaul in Figure 24 we can see that there is an overall decrease, as we also could see from Table 20. But there are no obvious changes in trends month by month for the different equipment.

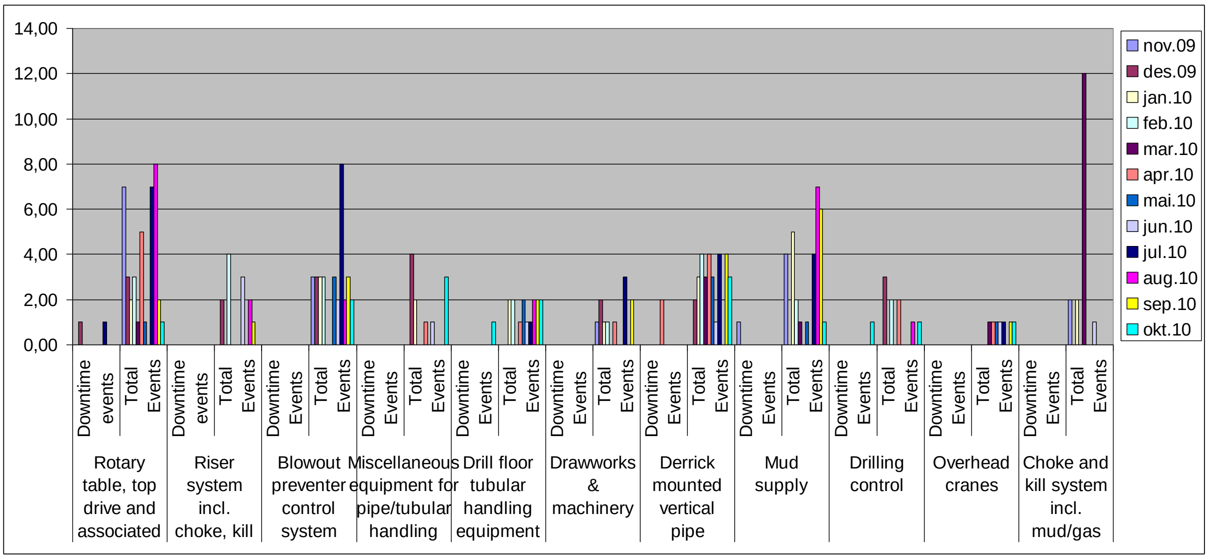

Figure 24: Historical corrective actions reported in IFS from November 2009 until October 2010 sorted by equipment groups and consequences

The downtime after the overhaul is shown in Figure 25 and the monthly average was approximately 14 hours a month. This is a significant decrease compared to the last year before the overhaul, when it the monthly average downtime was 41 hours. It is a decrease in downtime of 27 hours a month or approximately 65%.

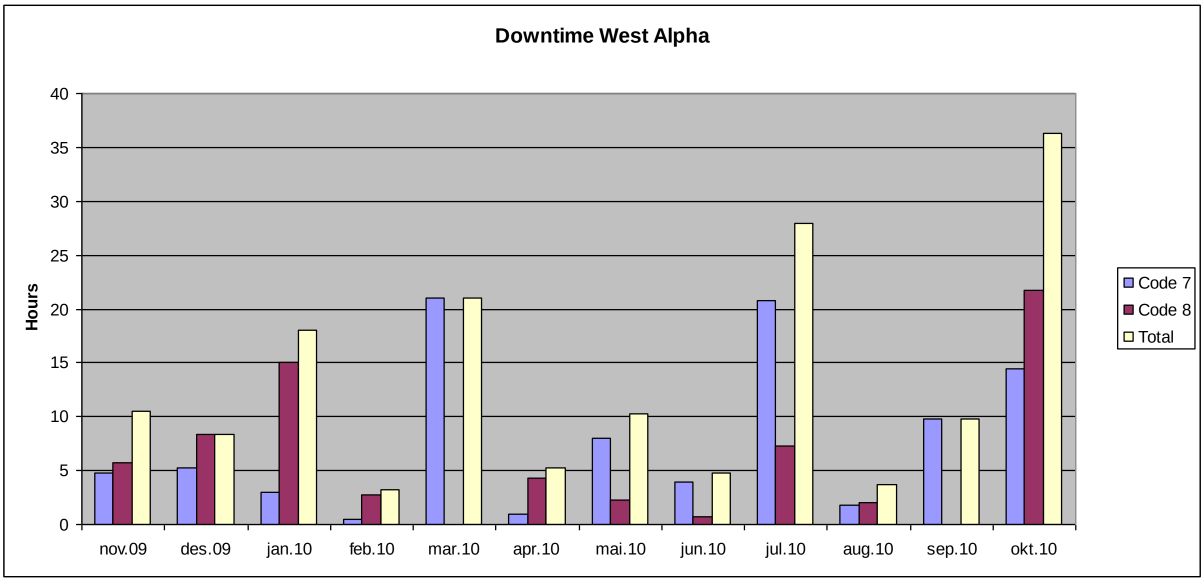

Figure 25: Historical downtime for West Alpha after last major overhaul

The last year before a major overhaul there might be an increase in maintenance and planned downtime in order to make the rig ready for the overhaul and following classing. But, as we can see from
Table 21 the difference is more or less equally big for both planned and unplanned downtime before and after the overhaul.

Table 21: Planned and unplanned downtime before and after West Alpha's last major overhaul

	Before	After
Code 7 (planned downtime)	22,5 hours/month	8 hours/month
Code 8 (unplanned downtime)	18,5 hours/month	6 hours/month
Total	41 hours/month	14 hours/month

4.5.2 West Venture case study

West Venture was docked for major overhaul and classing in 2005, returning to normal operation in May 2005 and the next major overhaul and classing was in 2010.
We have looked at how the downtime and failures have been in the period between these overhauls, from May 2005 until the end of 2009.

After each major overhaul we would expect the rig to perform at its maximum and the downtime and downtime events to be at its minimum. As time goes and we get closer to the next major overhaul we would expect an increase in downtime and downtime events, with a peak just before being overhauled. Some of this expected pattern could be observed in the West Alpha case study in the previous chapter.

When we analyze the downtime data, collected from DODA, for the period after West Venture`s overhaul in 2005 we get Figure 20 and Figure 27. Here we can see a slight decrease in the monthly average downtime, which is unexpected. If we look at average downtime the first 6 months after the overhaul in 2005 and the last six months in 2009 we get an average of around 18 hours/month in both periods. The average monthly downtime from the overhaul until 2010 is approximately 30 hours/month, but if we choose to ignore the months with un-characteristic high downtime (above 60 hours/month) we get an average of 18 hours/month.

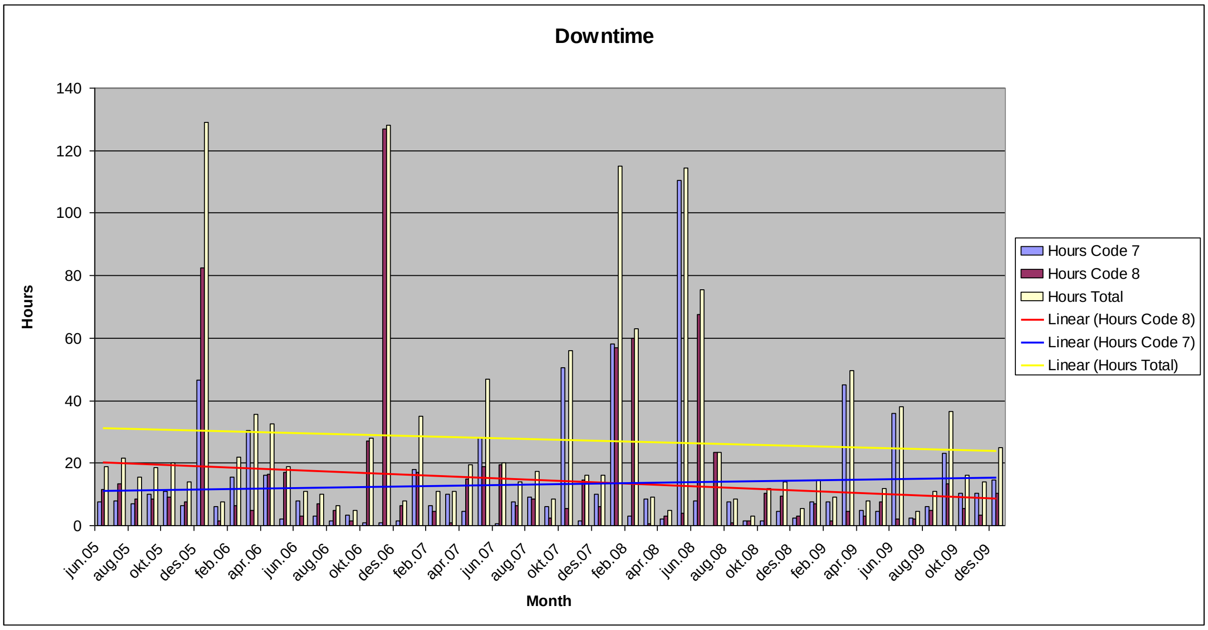

Figure 26: West Venture monthly average downtime sorted by Code and month

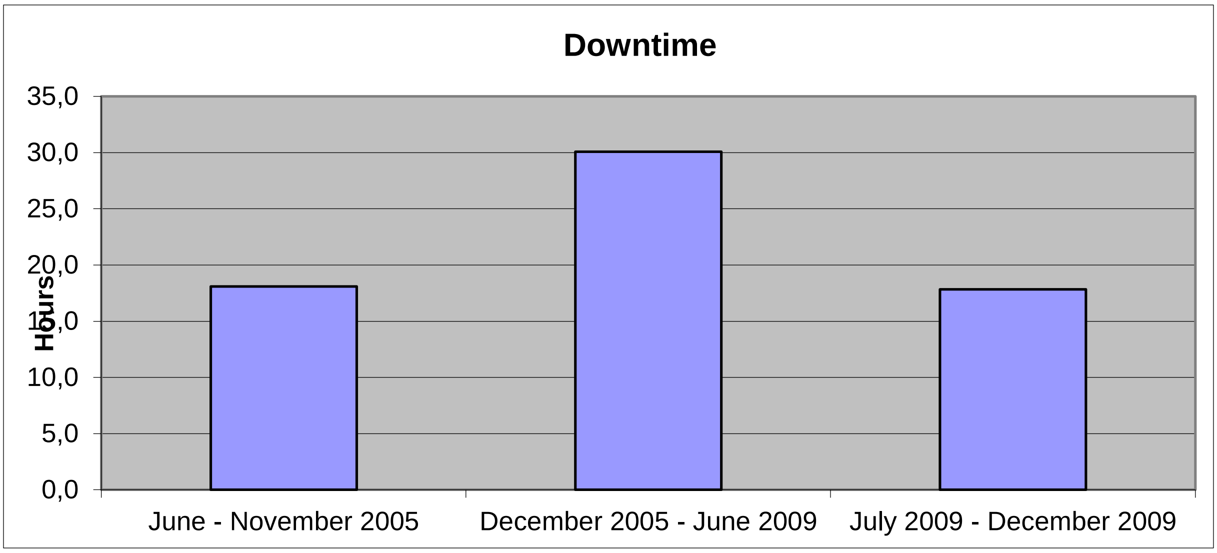

Figure 27: West Venture 6 month average downtime

There is a total of 6 out of 55 months (11%) with what we define as uncharacteristic high downtime, contributing with a total of 626 hours of downtime or 38% of the total downtime. Table 22 lists the uncharacteristic months and the corresponding data; if we compare this to the rest of our gathered data we get Table 23.

Table 22: Downtime in hours versus number of downtime events for months with uncharacteristic high downtime

Month	Downtime (hours)	Number of downtime events
December 2005	129	21
November 2006	128	43
January 2008	115	26
February 2008	63	27
May 2008	115	12
June 2008	76	25
Total	**626**	**154**

Table 23: Average monthly downtime versus average monthly number of downtime events from January 2005 to December 2009 compared to average for months with downtime exceeding 60 hours

	Average monthly downtime (hours)	Average monthly number of downtime events
June 2005 – December 2009	30 hours	13
Uncharacteristic Months (downtime over 60 hours)	104 hours	26

We have over three times as high average monthly downtime, but only twice the amount of events in the uncharacteristic months as in the rest of the period. When we look closer at the reports we can also see that most of the events in the uncharacteristic months are directly related with the same cause. We can also see that in May 2008 there was performed planned maintenance on BOP causing most of the downtime this month.

If we combine these findings with the trends in downtime we found earlier it seems like frequency of less severe downtime events have been quite constant in the entire period. The reason for the slightly decreasing downtime trend we discovered in Figure 26 is the uncharacteristic months. These uncharacteristic months have downtimes that, in large parts, are caused by a single root event with several directly related events caused by this root event. It also seems like these uncharacteristic months and events are just as likely to occur straight after a major overhaul as four years after and straight before next overhaul.

If we look at the amount of reported corrective actions in IFS from the overhaul in 2005 until 2010 we get Figure 28. There are no evident trends here; the monthly number of reports fluctuates randomly around an average of 14 reports a month. If anything, there is a slight decrease in the number of reports, but this decrease is too small and the fluctuations too big for us to say it is anything else than random.

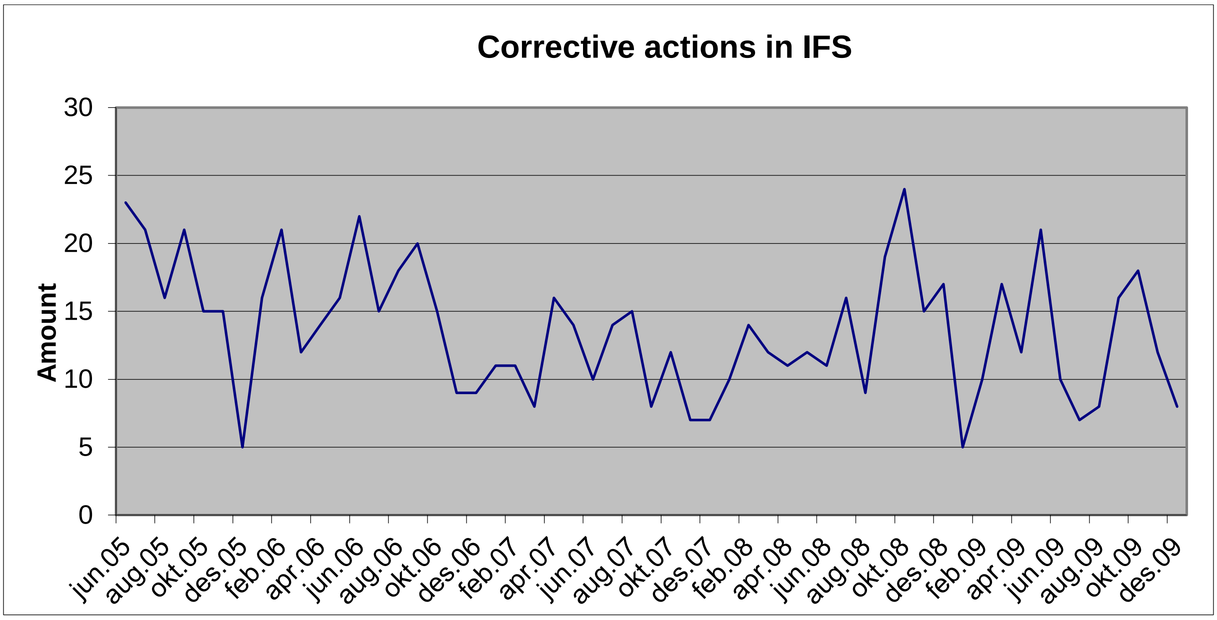

Figure 28: Corrective actions reported in IFS from June 2005 until December 2009 for West Venture

Based on these findings it is hard to determine how much of an impact the major overhaul has had on the downtime of West Venture. It does however seem like the period between the overhauls could have been longer since we are unable to find any obvious changes in failure frequency or downtime between the overhauls.

4.6 Spare part consumption

In order to look for any correlations between spare part consumption and downtime we have analyzed the spare part consumption on the European rigs for the 11 SFI groups causing the most downtime.

When we got the raw data from NADL regarding spare part consumption we soon discovered that a large percentage of the spare part orders were missing information on price, making the statistics subject to large uncertainties. However, the percentage of spare part orders lacking information about price seems to be fairly constant through time; therefore it can be used to look for any trends over time. The fraction of orders lacking information also seems to be similar across the different SFI groups. Therefore we conclude that the data can be used to compare the average cost of spare parts for each group against each other.

The overall spare part consumption measured by its cost has been decreasing since January 2008 as we can see from Figure 29. There are two months that stand out in this figure; April 2009 and August 2009, with respectively 12.1 mill. NOK and 11 mill. NOK.

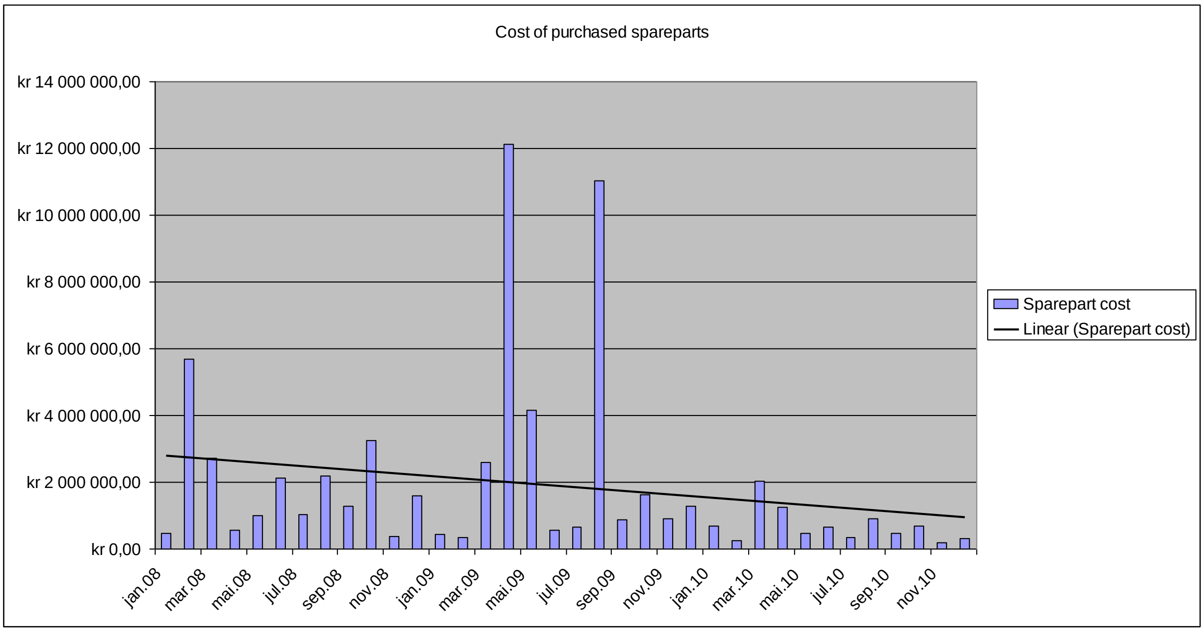

Figure 29: Total cost of spareparts on the european rigs for the top 11 SFI groups

For April 2009 10.8 mill NOK of the 12.1 mill NOK are caused by one single SFI group; Rotary table, top drive and associated equipment, as shown in Figure 30. This group also caused 24% of the total downtime in from January to October in 2009.

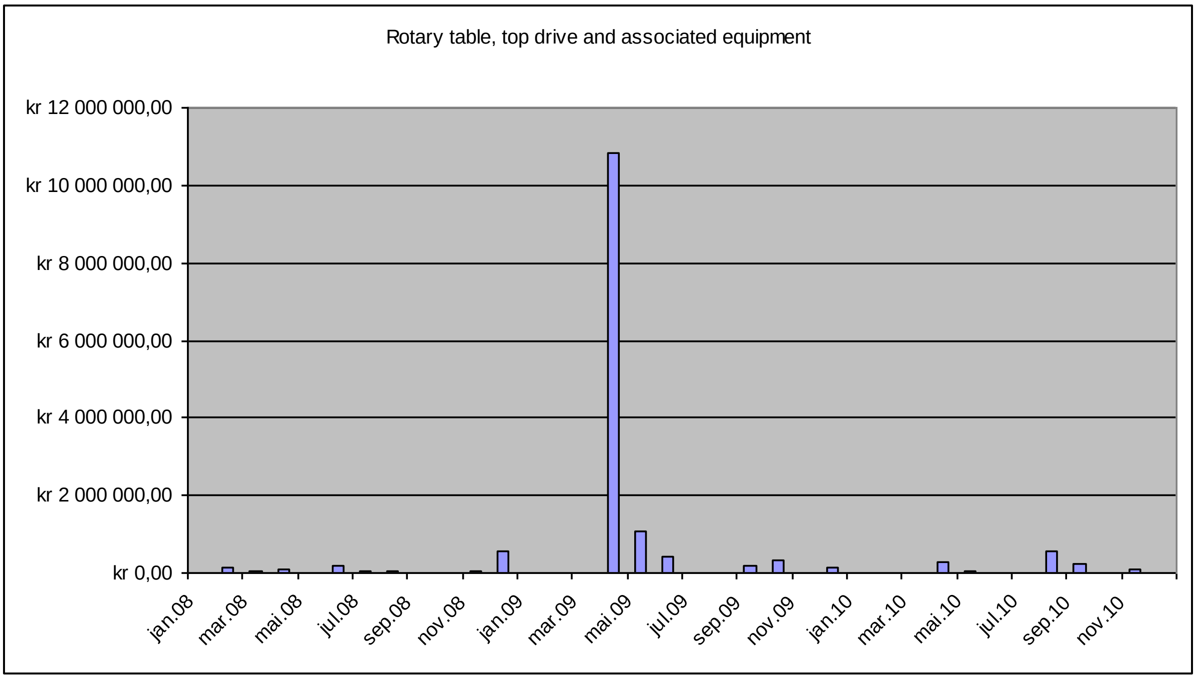

Figure 30: Total cost of spareparts on the european rigs for Rotary table, top drive and associated equipment

For August 2009 9.6 mill. NOK of the 11 mill NOK are caused by equipment in the riser system incl. Choke, kill and booster lines, as shown in Figure 31. This group caused 16% of the total downtime between January and October in 2009.

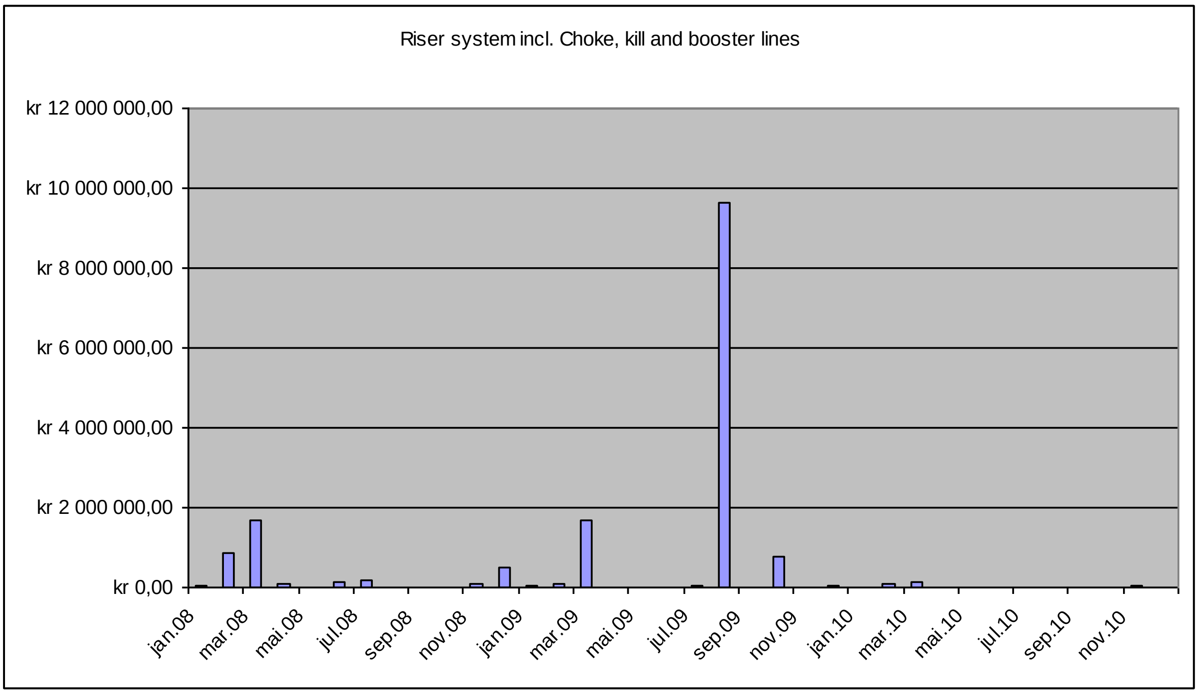

Figure 31: Total cost of spare parts on the European rigs for Riser system incl. Choke, kill and booster lines

The overall spare part cost for the different rigs are shown in Table 24. Here we can see that West Navigator have almost three times as high total costs as the second worst rig. If we look at the downtime of the different rigs we can see that West Navigator is dominant, with over 8 times as high downtime as the second worst rig for 2008 and almost twice as high downtime as the second worst for 2009.

We were not able to get a hold of the correct spare costs for West Venture when this thesis was written.

Table 24: Spare part costs from January 2008 until December 2010

	West Navigator	West Alpha	West Phoenix	West Venture	West Epsilon
Rotary table, top drive and associated equipment	1 995 918	788 375	11 351 453	0	1 381035
Riser system incl. Choke, kill and booster lines	12 498 124	3 721 756	493	22 374	1
Blowout preventer control system	10 725 641	3 089 064	80 825	257 655	146 668
Miscellaneous equipment for pipe/tubular handling	2 280 136	87 003	17 172	0	2 957
Drill floor tubular handling equipment	547 919	42 267	16 783	0	185 711
Drawworks & machinery	358 972	649 033	0	0	365 442
Derrick mounted vertical pipe handling system	341 131	345 607	404 980	0	334 496
Mud supply	1 419 603	1 057 391	920 988	0	1 364 950
Drilling control	298 258	273 005	184 229	0	411 509
Overhead cranes	130 207	220 231	419 615	0	47 500
Choke and kill system incl. mud/gas seperator	7 628 725	201 909	166 151	0	236 491
Total	38 224 639	10 475 645	13 562 689	280 029	4 476 764

Looking at the total spare part costs for our chosen SFI groups and comparing them to the group's downtime and loss of income due to downtime between January and October 2010 we get Table 25. There is no evident link between the spare part cost and downtime cost for the different groups that we can see in this period.

Table 25: Downtime vs. spare part cost for the European rigs between January 2010 and October 2010

	Downtime	Spare part cost	Downtime cost (loss of income)
Rotary table, top drive and associated equipment	456 hours	1 152 197 NOK	58 356 346 NOK
Riser system incl. Choke, kill and booster lines	301 hours	235 247 NOK	70 129 618 NOK
Blowout preventer control system	225 hours	772 014 NOK	42 593 001 NOK
Miscellaneous equipment for pipe/tubular handling	79 hours	283 448 NOK	10 726 447 NOK
Drill floor tubular handling equipment	47 hours	201 104 NOK	5 755 904 NOK
Drawworks & machinery	38 hours	120 247 NOK	3 620 210 NOK
Derrick mounted vertical pipe handling system	42 hours	510 217 NOK	3 943 520 NOK
Mud supply	24 hours	2 364 872 NOK	3 902 360 NOK

Drilling control	14 hours	139 904 NOK	1 323 700 NOK
Overhead cranes	15 hours	138 406 NOK	1 036 000 NOK
Choke and kill system incl. mud/gas seperator	14 hours	1 788 864 NOK	1 359 641 NOK

When we look at the monthly spare part cost versus the monthly downtime cost between January and October 2010 we end up with Figure 32. There are no sign of any correlation between the spare part consumption and downtime cost here either.

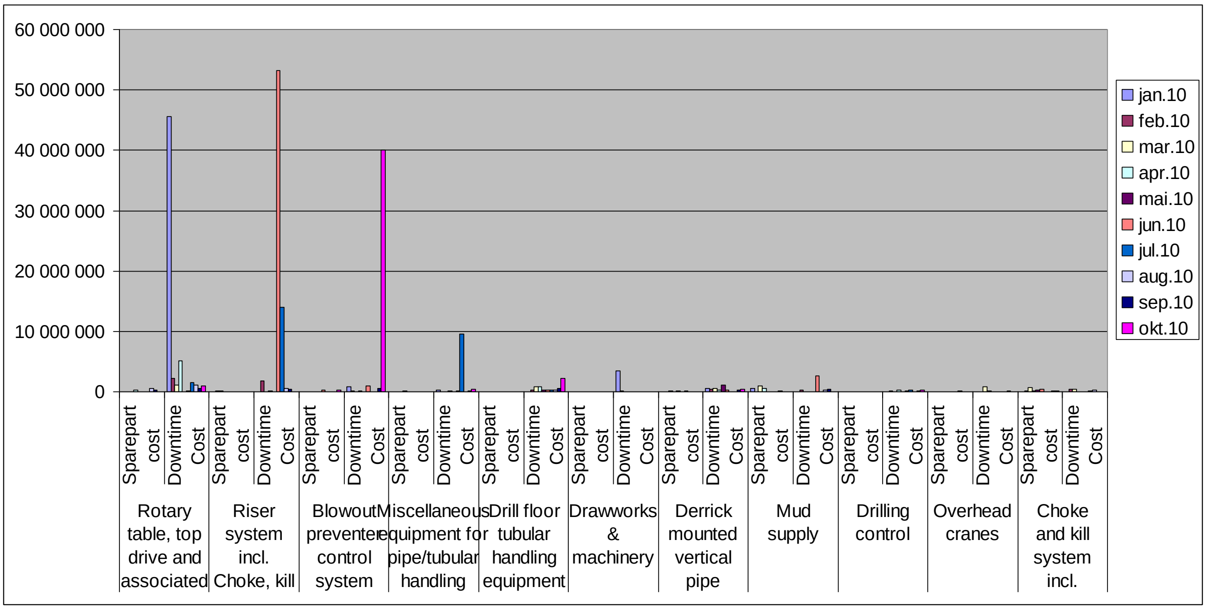

Figure 32: Spare part cost vs downtime cost between January 2010 and October 2010

We find it hard to make any conclusions about the influence changes in spare part consumption have on the downtime based on these results. We do however notice that three groups stand out, both with regards to downtime and spare part cost; the Rotary table, top drive and associated equipment group, the Riser system incl. choke, kill and booster lines group and the Blowout preventer control system group. These groups caused a total of 52% of the total downtime between January and October 2010, and 68% of the spare part costs when we limit the total cost to the cost contributed by our chosen 11 groups.

Despite not being able to see any corresponding trends in spare part cost and downtime events over time, we can see that the equipment causing the most downtime also have the highest spare part costs over time.

We also see that most of the spare part cost for these groups is concentrated over short periods of time and that the rest of the time the spare part cost is fairly equal to the other groups studied. This pattern is the same for the downtime caused by these three groups. Based on this we find it fair to assume that single events are likely to lead costly failures or other need for maintenance. Most of the other groups seem to have a more constant monthly spare part cost.

5. Data Quality

In order to successfully utilize gathered maintenance date from reports in the different databases the reports have to be of a certain quality and fulfill certain requirements. As a minimum we would say that one have to be able to easily identify the equipment, nature of the failure, work done, resources used, root cause and consequences experienced when we talk about maintenance related reports. The requirements to the content of the reports will depend on the intended use of the report.

We also have to take into consideration the resources needed, the personnel involved and the human-machine interface. Setting requirements to the content of the reports alone will not guarantee the data collected to be of a certain standard. We believe it is important to;

- make sure that enough resources are in place,
- that one has the support of the reporting personnel,
- that the personnel have the competence needed,
- and that the interface used is easy and understandable for all parties involved.

In this chapter we will share our experiences with the quality of the data from the three different databases used in this thesis. We have looked at the how well the reports fulfill the existing requirements within NADL and how well the reports fulfill the needs we have had when writing this thesis.

5.1 IFS

When issuing a corrective action in IFS these questions and descriptions should, in our opinion, be answered:

- Does the corrective action involve repairs?
- Does it involve spare parts?
- When is it to be executed?
- Have it, or will it, lead to down time (experienced consequences)? If not, could it have led to down time if in another operational phase (potential consequences)?
- Estimation of downtime.
- What equipment is involved?
- Time used on the action
- Operation mode of equipment involved
- Description of failure (should be short and to the point)
- Description of wanted action
- Description of action performed and experiences made

The descriptions should be written in such a way that they easily can be sorted, analyzed and used by management.

Today internal guidelines for IFS dictate that most of this information should be filled out, but the potential consequences and operation mode of the equipment is neither a requirement nor option.

When going through IFS today checking the quality of the issued corrective work orders some issues were found:

- A high percentage of the work orders lack information about downtime
- Potential consequences not a part of the reports
- Very high amount of work orders miss fault description
- Many work orders lack work description
- Many work orders lack work details
- Operation mode not a part of the reports
- Spare parts and repair not a part of the reports

To check how well the reports correspond with the existing guidelines for work orders in IFS we did a quantitative study of reports with missing information. This quantitative analysis over the entire lifecycle of IFS gave us Table 26, the average percentage of reports lacking vital information is here very high. After some research we found that the guidelines had been altered several times since the beginning, we therefore decided to do the same analysis over again, but this time only for 2010. As one can see from Table 27 the numbers here is much lower than from the first analysis.

Table 26: Work orders missing information in percentage

	Missing fault description	**Missing work description**	**Missing work details**	**Missing downtime info**
Alpha	41%	13%	19%	37%
Epsilon	43%	27%	30%	43%
Navigator	23%	26%	11%	31%
Venture	27%	31%	14%	31%
Phoenix	20%	27%	4%	34%
Average	**31%**	**25%**	**16%**	**35%**

Table 27: Work orders missing vital information in percentage for 2010

	Missing fault description	**Missing work description**	**Missing work details**	**Missing downtime info**
Alpha	24%	8%	1%	8%
Epsilon	11%	15%	2%	2%
Navigator	9%	21%	2%	2%
Venture	22%	30%	1%	3%
Phoenix	14%	34%	2%	12%
Average	**16%**	**22%**	**2%**	**5%**

When we compare the analysis for 2010 to the analysis of the entire life cycle we get Table 28. Here we again see a significant improvement in the quality of the reports. Most WO`s now contain work details and downtime information and there is a significant increase in WO`s containing fault description. There is still a large amount of WO`s missing work descriptions, here there have been little improvement in 2010. The reason for both the high percentage missing fault descriptions and the high percentage missing work descriptions can be found in the requirements to the reports.

In our opinion both fault description and work description should be required for any corrective work order in IFS.

Table 28: Percent improvement in 2010 compared to life time average

	Fault description reporting	Work description reporting	Work details reporting	Downtime reporting
Alpha	42%	38%	95%	78%
Epsilon	74%	44%	93%	95%
Navigator	61%	19%	82%	94%
Venture	19%	3%	93%	90%
Phoenix	30%	-26%	50%	65%
Average	**45%**	**16%**	**83%**	**84%**

5.2 SYNERGI

All rigs have to report incidents that cause downtime in Synergi; the reports are the responsibility of the Rig Manager and quality checked by an onshore technical administrator. Since Synergi first was taken into use in the beginning of 2010 there has been a high focus on the quality of the reports. All reports have been quality checked by the onshore technical administrator and there has been a continuous dialogue between the rigs and the technical administrator and monthly reports have been made.

Every month there is made and distributed a report on the quality of the reports in Synergi. These reports show a significant improvement since the beginning of 2010 with almost all reports fulfilling the internal requirements when this thesis was written.

The data used from Synergi in this thesis was from 2010 and we could clearly see an improvement in the quality as we worked our way from the beginning of 2010 until the end. Especially we noted that the root causes and actions done was of variable quality in the start, but significantly better in the end, fulfilling all our needs.

5.3 DODA

DODA (Daily Operation Database Application) contains daily operational data from each rig. Each rig reports rig status, drilling progress, weather conditions and various HSEQ issues daily to DODA. In addition each rig also have a weekly report that contains a short summary of the daily reports for the last week, month, quarter, year, current and last week. The weekly report also contains comments from the platform manager on last week’s activities and plans for the week to come.

In order to track the downtime of rigs, at what times the downtime occurred, if it was planned or unplanned and to fin short descriptions of the causes of the downtimes DODA worked more or less flawlessly for us in this study.

5.4 Correlation between the databases

All unexpected downtime that requires some sort of work to be done on equipment in order to regain operation should be reported as a corrective action in IFS, this report should be marked as causing downtime in IFS. If we compare the reported downtime due to corrective actions in IFS with the reported downtime in Synergi we get Table 29. We can see that there is a very small amount of days that have reported downtime in IFS and Synergi.

Table 29: Reported downtime days in Synergi vs reported corrective actions in IFS on the same dates

	Correspondence between days with IFS reports and downtime			
	Downtime Days reported in Synergi	With Downtime Report in IFS	With Unknown Report in IFS	Percentage with IFS downtime report
Alpha	43	3	7	6,98 %
Navigator	110	20	9	18,18 %
Epsilon	43	9	1	20,93 %
Venture	28	0	6	0,00 %
Phoenix	61	10	25	16,39 %
Total	285	42	48	14,74 %

It is however important to note that the downtime reported in Synergi in large parts don’t require any work orders in order to regain operation. If we assume that all the maintenance related downtime requires a work order in order for the rig to resume operation there should be a total of approximately 35% percentage of the days with downtime events reported in IFS. This number is likely to be a little high since the work done in order to regain operation in some cases don’t require a work order. It should be fair to assume that the percentage should be fairly equal for all the rigs and not as varying as the case is here, going from 0 to 21%. It seems like West Venture and West Alpha have unnatural low amount of IFS downtime reports on days with downtime compared to the rest of the rigs.

If we look at days with corrective actions reported as leading to downtime in IFS and not registered in Synergi we get Table 30. Since we know that the downtime information in Synergi is quality assured and checked against DODA we assume it to be correct. The IFS reports of downtime events that we can see in Table 30 must therefore contain wrong information about the time of the event or if it has caused downtime.

Table 30: Downtime reports of downtime on days with no registered downtime in Synergi

Rig	Days	IFS reports
Alpha	5	6
Navigator	12	14
Epsilon	10	11
Venture	6	6
Phoenix	5	12
Total	38	49

The downtime information in DODA is quality assured by both onshore and offshore personnel and the downtime information in Synergi is checked against DODA again. This makes the information in both Synergi and DODA to be of a satisfying quality.

5.5 Conclusion

In order to effectively being able to analyze data from a database we experienced that the data must be in such a format that it easily can be sorted and key data extracted. For our use and by the requirements within NADL we found both DODA and Synergi to contain data with satisfying quality. The data we gathered from IFS was, however, of very variable quality, often not meeting our criteria's and being insufficient for us to successfully do all our intended analyses.

The reasons for this might be many, but we believe some of the key reasons are:

- The reporting in DODA is not only used internally, but also externally against contractors for financial reasons. The focus and resources used on the quality of the data in this database have, as a consequence of this, been high.

- When NADL started to gather downtime information in Synergi they decided to closely follow up on the quality of the received reports, having onshore personnel that gave individual feedback to each rig as well as making weekly and monthly reports of the quality. We can clearly see that having such individual feedback as well as weekly and monthly reports has increased the quality of the reports.

- Common for both DODA and Synergi is the clearly defined demands and guidelines for the reports. The data we have used from both Synergi and DODA have been for downtime with direct economic consequences for the company.

- The data we have used from IFS have mainly been for corrective actions, and in large parts without the same direct economic consequences as the downtime reported in DODA and Synergi.
- The guidelines have not been as clearly defined and the interface has not been as user-friendly as it could have been. Both the interface and the guidelines have been improved lately and one can clearly see the effect of this on the report quality, especially in 2010.

The improvement in IFS is also explained by the onshore Maintenance and Logistics Manager in the following way:

"Since app. summer 2009 have we focused on improvements with regards on registration and reporting of corrective actions. During 2011 will we held course within IFS for all end users on our units. Some need refresh course and new employers need basic course.
Corporate have also started an improvement project within IFS and the goal is to make IFS more user friendly and implement permission control. Permission control will help us to secure good quality on all new corrective actions before they are released."

This statement matches and supports our findings and conclusions regarding report quality in IFS good.

6. Analysis verification and validation

In order to evaluate the maintenance management and to verify and validate our analysis's we have interviewed some key personnel both offshore and onshore.

6.1 Interview with key personnel

In order to better understand and interpret our collected and analyzed data we have interviewed some key onshore and offshore personnel about their view on the data collected, how the maintenance have been done in NADL, how it should be done and the quality and importance of reporting. We also wanted to check how the key personnel's personal beliefs corresponded with the collected data, and if there were any differences between the onshore and offshore personnel. The questionnaires can be found in Appendix B – Questionnaires.

From the collected data we found a significant decrease in downtime events around 2006 which we could not see any obvious explanation for. The interviews tell us that this decrease most likely is caused by the introduction of first line maintenance.

When asked if not only the occurred consequences, but also the potential consequences should be evaluated when classifying a failure, almost 90% answered that the potential consequences also should be evaluated. The main reasons they give for this is that it could prevent downtime and reduce the risk for accidents by being able to perform better analyzes to determine frequencies, mean time to failure etc. and adjusting the maintenance schedule accordingly.

When it comes to report quality it is clear that the maintenance planners for the different rigs are responsible for ensuring the quality of reports in IFS. But, when we asked the offshore personnel how satisfied they are with the feedback they receive on the quality of these reports we discovered that this feedback is lacking for some of the personnel. The personnel that have received feedback on the quality did not find the feedback very satisfying and ranked it as 3 out of 6, where 6 is very satisfied.

The onshore personnel feel the biggest challenge in order to improve the report quality from the offshore personnel is the 2-4 schedules, different cultures on different rigs and IFS interface. Not using IFS and reporting for four weeks at the time makes it harder to get good reporting routines. The offshore personnel often come from different previous rig companies with different cultures and routines when it comes to reporting, which affects their current reports. Last, but not least, choosing the best combination of mandatory fields in IFS for reports have been, and still is, a challenge.

Offshore personnel feel that the onshore personnel best can help them improve the report quality by giving individual feedback on report quality, having one clear single point of contact and improve the IFS interface.

The offshore personnel are also often unsure on how the IFS reports are being used in order to improve maintenance. Some does however use historical data on the equipment in order to better plan future jobs and maintenance. The onshore personnel have mainly used this data for new processes and procedures under preparation and start-up. It has not been a part of any continuous process or any good system until now. NADL is working towards a reliability centered maintenance (RCM) program (Moubray, 1997), where the maintenance will be evaluated continuously based on reports and experiences from the different rigs. The implementation of RCM is a repeating theme when interviewing the onshore personnel.

When we ask how much of the total downtime the different personnel believe is caused by insufficient maintenance almost all believe it to be one of the least causing root causes. Our analysis's show that insufficient maintenance was one of the main contributors to downtime events in 2010 being the cause of around 36% of the total number of downtime events. But, if we look at the amount of downtime hours insufficient maintenance caused we get approximately 11% of the total downtime.

When asked to rank the contribution from seven different root causes the onshore personnel believed poor design to be the main contributor, while the offshore personnel were far less united in their beliefs. The ranking from the offshore personnel didn't show any common belief about the main contributor, in total 5 of 7 root causes were ranked as main contributor from the offshore personnel. The two root causes that weren't ranked as main contributor in any interview were insufficient maintenance and poor quality. In total they believe insufficient maintenance to be on fifth place in downtime contribution, and on average fourth place. The overall ranking from the interviews versus the actual results from the analyses done in this paper is shown in Table 31.

Table 31: Ranking of root causes causing downtime by onshore and offshore personnel

Causes of downtime	Onshore Personnel	Offshore Personnel
Poor design	1	2
Insufficient maintenance	4	5
Poor quality	2	2
Poor planning	6	1
Equipment operational limitations exceeded	2	2
Lack of tools	7	7
Lack of spare part	5	6

On average the interviewed offshore personnel seem to be using around 25% of their working hours on reports, or 3 hours each day. When asked to rank how they feel the time they use on the reports are worth it from 1 to 6, where 6 is very much, we get an average of 4.3.

Offshore personnel working in technical performing positions such as electricians does not see the value of reporting downtime in IFS, while offshore personnel in technical leader positions see it as useful in order to use historical WO`s and improve maintenance routines.

When the offshore personnel were asked what they believe are the major challenges in order to reduce maintenance related downtime in the future we received many different answers. Replacing old equipment, getting spare parts faster delivered, more people and training are some of the answers.

When asked how NADL best can overcome these challenges we also receive many different answers. More mechanical personnel onshore, increased focus on preventive maintenance, use planned hours, increased focus on competence and more maintenance were some of the answers from the offshore personnel.

The onshore personnel were asked how they intend to reduce maintenance related downtime, and answered that they are introducing RCM, increasing focus on KPI`s, internal training and improving standard job descriptions.

6.2 Conclusions from interviews

When we compare the interviews with our analyses of the downtime root causes it is clear that both onshore and offshore personnel have a pretty good understanding of how much of the total downtime is caused by insufficient maintenance. The ranking from the onshore and offshore interviews is fairly similar, with the exception of one root cause; Poor planning. It is interesting that offshore personnel rank poor planning as the main contributing root cause, while onshore personnel rank it as the second least. The reasons for this might be many, but it is something that should be studied further by NADL. Having good communication, common goals and beliefs amongst offshore and onshore personnel is in our opinion important in order to ensure the organization to perform at its best. It might seem like there is room for improvement in the communication between the onshore planners and the offshore personnel. Improving this communication might help correct the impression offshore personnel have regarding poor planning being the number one cause of downtime.

Both onshore and offshore personnel believe that potential consequences as well as the occurred consequences should be reported. The higher position the interviewed personnel have the more they seem to value not only the occurred, but also the potential consequences.

When it comes to the quality of the reports, the interviews revealed that the offshore personnel don’t feel they get the support they need in order to improve this. This is, in our opinion, a matter of improving the communication between responsible personnel onshore and the reporting personnel offshore. Personal feedback from responsible parties onshore to the responsible and performing parties offshore is in our opinion the best way to do this.

The biggest and most effective change in maintenance management historically in NADL accordingly to both offshore and onshore personnel is the introduction of 1-st line maintenance. First-line maintenance was introduced around 2006 and our analyses support this belief and show a decrease in downtime events after 2006. Before 2006 all lubrication and visual inspection was done on a one month basis. With the introduction of first line maintenance there were developed a detailed maintenance program with descriptions of what and when to inspect and lubricate. The schedules now become adapted to the specific equipment, either being daily, weekly or each other week instead of monthly for all. With the alteration in schedules the maintenance inspection now involved more personnel, since the increased frequency made more shifts involved. Having several different persons inspecting and lubricating the equipment instead of one increase the chances of detecting any developing failures. One soon experienced that with the introduction of first line maintenance one were better able to detect failures before they occurred. Especially developing failures in hydraulic hoses were detected more frequently before failure.

7. Summary and discussion

The aim of this thesis is to improve the way failures caused by insufficient maintenance are being managed and reported on drilling rigs and thereby reducing the overall downtime and related cost for the rigs.

The thesis have been trying to look into the quality of reports for critical and non-critical failures, identifying the potential consequences of non-critical failures and identifying downtime trends and possible reasons for these.

The results of the analysis`s, interviews and information gathering done in order to find this is discussed in this chapter.

Main contributors to downtime

We found poor or insufficient maintenance to be the root cause of around 36% of the total downtime events, but only 10% of the total downtime costs between January and October 2010.

Poor quality and design were the two main root causes in the same period of time; both are typically associated with 3rd part suppliers. 3rd party suppliers were responsible for 68% of the downtime in the same period of time.

Of equipment we discovered that 15 groups were responsible for 94% of the total downtime for the rigs studied between January and October 2010. Of these 15 groups we ended up with 11 groups when we only took into account maintenance related downtime, these 11 groups are listed in Table 32.

Table 32: Our chosen 11 equipment groups for further studies and the related SFI group code

Equipment Group	SFI group code
Rotary table, top drive and associated equipment	313
Riser system incl. choke, kill and booster lines	335
Blowout preventer control system	332
Miscellaneous equipment for pipe/tubular handling	347
Drill floor tubular handling equipment	342
Drawworks & machinery	312
Derrick mounted vertical pipe handling system	341
Mud supply	325
Drilling control	311
Overhead cranes	362
Choke and kill system incl. mud/gas separator	336

Of these 11 groups one group contributed with more downtime, calculated by cost, than the rest combined; the Rotary table, top drive and associated equipment group.

Despite poor or insufficient maintenance being the root cause in a large percentage of the downtime events it is not causing as long downtime as other root causes. The downtime caused by 3rd party suppliers, typically poor quality and design causes far more downtime hours.

Of the maintenance related downtime we clearly see that there are a few groups contributing with almost all the downtime. One should, in our opinion, start by looking closely at the Rotary table, top drive and associated equipment group, which contributed with over 60% of the maintenance related downtime costs.

Changes in downtime and possible reasons for this:

There has been a decrease in yearly downtime events since 2005, with a significant reduction between 2006 and 2007. When we saw this decrease in downtime events we expected to see a similar decrease in downtime hours, with a significant reduction between 2006 and 2007 also here. But when we look at the downtime hours for the different rigs we are not able to see this same significant reduction between 2006 and 2007, instead we discover an increase in downtime hours from 2005 until 2008. This downtime is however largely influence by one single rig, West Navigator, and when we choose to ignore the contribution from this rig we get another picture. We then get a slight reduction in downtime from 2005 until 2010, but still no significant decrease between 2006 and 2007. We analyzed the spare part consumption, corrective actions reported and planned maintenance without finding any trends able to explain the reduction in downtime events between 2006 and 2007. From a purely analytical perspective this reduction seemed to be without any obvious reason, but a change that large that persists is, in our opinion, not random. Through interviews with key personnel we found that NADL had introduced first line maintenance in the same period of time as the significant decrease in downtime events had occurred.

The introduction of first line maintenance altered the existing routines and schedules for visual inspection and lubrication of the equipment on the rigs. This alteration seems to have decreased the number of downtime events without decreasing the downtime to the same degree. This can be explained by the severity of the type of downtime events reduced by the introduction of first line maintenance. Since first line maintenance mainly is about visual inspection and lubrication the decrease in downtime events most likely have been caused by a reduction in failures of hydraulic hoses. Failures in hydraulic hoses can cause downtime, but to replace the hose and regain operation is rarely a very time consuming operation.

The contribution to the overall downtime from smaller and less critical failures such as failures in hydraulic hoses is very small compared to the contribution from a few highly critical equipment groups. Here three groups stand out as especially critical;

- Rotary table, top drive and associated equipment
- Riser system incl. choke, kill and booster lines
- Blowout preventer control system

When we exclude any downtime not directly related to insufficient or poor maintenance the Rotary table, top drive and associated equipment group stands out with over six times as high cost/downtime as the second group. This group has the highest number of downtime events and the highest average cost/downtime for each event. It, alone, caused around 60% of the maintenance related downtime between January and October 2010. We found this group to have a decrease in planned maintenance reports in IFS from 2004 until today. One would expect that the planned maintenance on this group would be increasing and altered in order for it to become less dominant in its downtime contribution.

Planned downtime versus unplanned downtime

Since planned maintenance is subject to contractual agreements it is hard to make any decisive conclusions based on the reported planned downtime. We can however see signs of a pattern where an increase in planned downtime reduces not only the unplanned downtime but also the total downtime. Planned downtime isn't caused by any instant failure in equipment and has to be reported and agreed upon with the contractor at least 48 hours prior to the downtime. We believe that the reduction in the overall downtime when increasing the planned downtime is because we are able to perform maintenance and inspection on equipment that we in normal operation are unable to perform.

Spare Part consumption and possible influence on downtime:

The spare part consumption has been slightly decreasing, but we have not found any obvious link between changes in the spare part consumption and changes in downtime hours or events. We did however discover that two of the groups we found to be especially critical with regards to downtime also had the highest consumption of spare parts measured by its cost. Both the Rotary table, top drive and associated equipment group and the Blowout preventer control system group have a high spare part consumption as well as downtime cost, especially the Rotary table, top drive and associated equipment group. As for the downtime caused by these groups large parts of the consumption is concentrated over short periods of time. Based on this we believe it is fair to assume that these groups are more likely to experience single severe failures, causing high spare part consumption and downtime, than the other groups in this study.

We also see that the Mud Supply group has the second most average downtime cost per event while having the highest spare part consumption measured by its cost. There have not been many downtime events caused by this group, but the few events that have occurred have been expensive. So despite having the highest spare cost it is, in our opinion, worth the cost when you look at the cost of a possible downtime event.

The Choke and kill system incl. mud/gas separator group have the second highest spare costs, but this group have a very low average cost per downtime event. We do however only know about the downtime costs for a single event for this group, making a poor basis to make any conclusions based on. We do however believe that the spare part consumption on this group should be evaluated against the failure rate as it can seem as the maintenance costs more than its preventive value.

If we compare the spare part costs for each rig against its downtime in 2010 we see that West Navigator dominates both. It is hard to find any reasons for this, but we suspect that West Navigator dominates the spare part costs since the downtime events it have experienced have required high quantities of spare parts and on expensive equipment. It is, in our opinion, fair to assume that spare parts on highly critical equipment often are more expensive than for less critical equipment. The higher criticality the equipment has, the higher the requirements for the equipment itself and its spare parts should be. For the other rigs it seems like the higher the spare part costs are the lower the downtime is.

Changes in planned maintenance and possible effects on downtime

When we started to analyze the amount of planned maintenance done on our selected equipment groups we expected to see changes from year to year as a sign of the maintenance program being continuously improved. We hoped that these changes could be directly related to changes in the downtime and that we could use this information to further suggest improvements. We could see some changes from year to year in the amount of planned maintenance carried out, but it changes were quite small and did not correspond with any changes in downtime events or hours.

The biggest changes have been for the Rotary table, top drive and associated equipment group and the Mud supply group, with a reduction of around 25% in reported planned maintenance from 2004 until 2010. We cannot find any sign that this reduction in planned maintenance has influenced the number of downtime events or hours for the same groups.

Major overhaul for classing and possible related effects on downtime

In order to investigate the possible effects a major overhaul have on the needed corrective maintenance and downtime we did two case studies; one for the year before and after West Alpha`s last major overhaul and one for the five years between the last two major overhauls for West Venture. We expected the results to be somewhat similar for both these cases; showing an increasing trend of corrective maintenance performed and downtime experienced between the overhauls.

The case study of West Alpha show a significant decrease in both downtime experienced and corrective maintenance performed the first year after the overhaul compared to the last year before the overhaul.

The case study of West Venture did not give us the results we expected. There was, if anything, a decreasing trend in the downtime experienced between the overhauls. The average monthly downtime was similar the first 18 months after the first overhaul as for the last 18 months before the second overhaul.

The average monthly amount of corrective actions performed between the overhauls fluctuated heavily, but there were no evident increasing or decreasing trend.

The West Alpha case clearly shows us that the major overhaul have had an impact on the downtime and needed corrective maintenance. We believe this to be the case also for West Venture, with the difference being that the overhaul made it possible for West Venture to keep a low failure rate between the major overhauls without reducing it as in the West Alpha case. For the West Venture case it can seem like the interval between the major overhauls could have been longer.

Non-critical failures and their potential

When we first started writing this thesis one of our intended goals was to discover any hidden downtime that could be related to insufficient or poor maintenance. We soon realized that the way corrective maintenance was reported within NADL made this difficult for us to achieve. The failures that don't cause rig downtime are only reported in IFS and the content and quality of these reports were insufficient for us to discover the potential of these failures.

It is, in our opinion, very important to identify not only the occurred consequences of the failure, but also the potential consequences. The same failure can be critical in one phase of the operation and non-critical in another phase, despite the operation of the equipment itself being similar. Since the operation of the equipment is similar the failures that are classified as non-critical could just as well have been critical. By ignoring this potential consequence of the failure we get a wrong picture of the probability of downtime. When setting up a maintenance program we strive to find the balance between the cost and the savings of the maintenance. It is therefore important that we get as correct as possible probabilities when we calculate the potential savings associated with the increase in maintenance. This is not only limited to the cost directly related to down-time, but also the indirect losses caused by loss in reputation and similar.

Quality of the reports and data used

Here we experienced large differences from database to database with DODA and Synergi providing data with good quality while the quality of the data in IFS strongly varied from report to report. The reports in IFS did in many cases not meet internal requirements and never our requirements.

In order to effectively being able to analyze data from a database we believe that the data must be in such a format that it easily can be sorted and key data extracted. For our use and by the requirements within NADL we found both DODA and Synergi to contain data with satisfying quality. The data we gathered from IFS was, however, of very variable quality, often not meeting our criteria's and being insufficient for us to successfully do all our intended analyses.

The reasons for this might be many, but we believe some of the key reasons are:

- The reporting in DODA is not only used internally, but also externally against contractors for financial reasons. The focus and resources used on the quality of the data in this database have, as a consequence of this, been high.

- When NADL started to gather downtime information in Synergi they decided to closely follow up on the quality of the received reports, having onshore personnel that gave individual feedback to each rig as well as making weekly and monthly reports of the quality. We can clearly see that having such individual feedback as well as weekly and monthly reports has increased the quality of the reports.

- Common for both DODA and Synergi is the clearly defined demands and guidelines for the reports. The data we have used from both Synergi and DODA have been for downtime with direct economic consequences for the company.

- The data we have used from IFS have mainly been for corrective actions, and in large parts without the same direct economic consequences as the downtime reported in DODA and Synergi.
- The guidelines have not been as clearly defined and the interface has not been as user-friendly as it could have been. Both the interface and the guidelines have been improved lately and one can clearly see the effect of this on the report quality, especially in 2010.

The improvement in IFS is also explained by the onshore Maintenance and Logistics Manager in the following way:

"Since app. summer 2009 have we focused on improvements with regards on registration and reporting of corrective actions. During 2011 will we held course within IFS for all end users on our units. Some need refresh course and new employers need basic course.
Corporate have also started an improvement project within IFS and the goal is to make IFS more user friendly and implement permission control. Permission control will help us to secure good quality on all new corrective actions before they are released."

This statement matches and supports our findings and conclusions regarding report quality in IFS good.

8. Suggested improvements

As a result of the information gathered and analyzed in this thesis we have been able to come up with some suggestions for improvements. These suggestions will be listed and briefly explained in this chapter.

Improve report quality

- Make sure that similar failures on the same equipment across rigs are reported similarly so they easily can be sorted out and used for further analysis.
    - What equipment and what type of failure should be chosen from a predefined list.
- Increased focus on personal feedback to the reporting personnel
    - Make the reporting personnel see the value in good report quality
    - Ensure the reporting personnel are notified about any changes in interface and reporting guidelines by having these posted on the intranet
    - Have focus on the language used. Everyone need to use the same terms and notations.
- Demand the reports of corrective maintenance to include potential consequences, possibly by a drop down curtain with a ranking choice of potential consequences. The ranking could be:
    - 1. Potential downtime above 24 hours
    - 2. Potential downtime 12-24 hours
    - 3. Potential downtime 6-12 hours
    - 4. Potential downtime 3-6 hours
    - 5. Potential downtime 1-3 hours
    - 6. Potential downtime 0-1 hours
    - 7. No potential downtime (default)
- Evaluate the way reporting is done in IFS today.
    - Only have one possible way to report corrective maintenance
    - Make as much of the input data as possible chosen from a predefined list
    - The predefined lists should be easy to understand and avoid having any option such as “others”. Having the option to report something under “others” can reduce the overall quality of the reports as the reporting personnel might use this even in cases where another option is valid. Therefore a set of valid options covering all possible needs should be defined, avoiding the “other” option
- Regular reports of the data quality in IFS should be made and distributed to all reporting personnel. These reports should reflect the report quality of the different rigs as well as technical sections of the rigs. Similar reports are made and distributed for the report quality in DODA today with good results.

Reduce downtime

- Increase focus on preventing failure on the most critical equipment groups
    - Especial focus on the Rotary table, top drive and associated equipment group
- Better control of 3rd part suppliers
    - Increased focus on inspection of delivered equipment throughout its production and at delivery
- Maximize the use of planned downtime as this seems to reduce the overall downtime

- Continuously gather and analyze maintenance data in order to optimize the maintenance routines and schedule. Use reliability centered maintenance.
- Improve the quality of the maintenance data in IFS.

Find and possibly reduce the number of hidden downtime events

- Make it possible to sort out failures that have the potential to cause rig downtime
    - Demand reported corrective actions in IFS to contain information about the potential consequences
    - Possibly export all reported downtime events and events with the potential for downtime into an own database
        - Collecting information from IFS, Synergi and DODA about all events causing downtime or with the potential to cause downtime
        - Must contain information about the failure type, equipment, severity and actions performed

9. Conclusion

During our work with this thesis we found the downtime caused by insufficient or poor maintenance to be low compared to other causes. The main contributor to downtime was caused by 3rd party suppliers and typically subject to poor design and quality of the delivered equipment. Increased inspection routines and stricter quality assurance of delivered equipment and manufacturers can help reduce this, it is difficult, if not impossible, to avoid this downtime with maintenance.

The introduction of first line maintenance on the rigs in 2006 has shown to significantly reduce the number of downtime events, but not the downtime hours to the same extent. This and further analysis tells us that the maintenance related downtime in large parts are dominated by single events on highly critical equipment, with the Rotary table, top drive and associated equipment group being the main contributor to downtime.
It is, in our opinion, a larger potential for reducing the downtime by increasing the focus and limiting the probability of these single events to occur than to try further limiting the number of less severe downtime events.

When there was an increase in planned downtime we found a decrease in the overall downtime, which suggest that more use of planned downtime is likely to reduce the overall downtime. Having a certain amount of planned downtime will therefore not only be beneficial for NADL, but also for the contractor(s), reducing the overall downtime and length of operation.

To better identify hidden downtime and use this to possible reduce downtime we found the existing data quality to be insufficient, especially for the years prior to 2010.

The data collected in DODA used in this report have direct economic consequences and are made both for internal use and external reporting. Accordingly the data gathered have received high attention in order to maintain the needed quality. The same can be said for the data we have used from Synergi, where regular reports and feedback of the report quality have been given by dedicated onshore personnel in order to improve the quality.

The introduction of downtime reports in Synergi have made it possible to more effectively analyze the causes of downtime and the actions taken, it proved to be a very effective tool when searching for root causes both by category and supplier.

The data collected from IFS is however not subject to such direct economic consequences and are only for internal use. This reflects in the resources used to ensure the quality and also the quality of the data itself when compared to existing internal requirements and guidelines. In addition we found the reports following the internal guidelines and internal requirements to be insufficient for us to properly use the data to find potential hidden downtime events and key areas to improve the maintenance on.

To improve the quality of the reports in IFS we identified a few key factors we believe to be vital:

- Using predefined criteria's for as many report categories as possible
- Limit the predefined criteria's to a minimum while still covering all possible needs without having the possibility to choose "other".
- Only have one way of reporting a corrective action, as opposed to two as of today

- Make sure the reporting personnel use the same terms and notations when reporting
- Improve the communication between reporting personal and responsible onshore personnel by giving individual feedback on report quality
- Make sure that all reporting personnel see the value of good report quality
- Make regular reports, weekly or monthly, of the quality of the reports in IFS that are distributed to all reporting personnel. The quality of the reports should be measured for each rig and for the technical sections, possibly also for the different shifts. Such reports will possibly make the reporting personnel more aware of the quality and see the value of the reports clearer; it will also make for internal competition between rigs, technical sections and shifts.
- Continue to improve the IFS interface with the aid of personnel feedback, making the interface easy and understandable for all users.

We believe these factors to potentially improving the quality of the reports measured against existing internal criteria's, but we also believe that the reports should contain a different set of information than what it does today.

In order to better minimize downtime and identify the criticality of equipment we believe that the potential consequences of a failure should be a part of any corrective maintenance report in IFS. This is already done for all hazards and accident situations by the Petroleum Safety Authority Norway (PSA), covering not all situations that have led to or could have led to damage to health, safety or environment under slightly altered circumstances (PTIL et al., 2002). This data is used done in order to minimize the amount of such events offshore.

Gathering all the data about downtime events and events with a potential for downtime caused by insufficient or poor maintenance in one single database can be a way to better determine the need of maintenance on different equipment. Such a database will make it possible to continuously analyze and improve the maintenance in order to limit the downtime. The transfer of lessons learned from rig to rig will also be more effective with such a database, since maintenance routines might be continuously updated and distributed to all rigs with similar equipment.

To sum it all up we believe that in order to reduce the maintenance related downtime; improving the data quality of work reports (IFS), evaluate and change the work report guidelines for IFS, have one database combining information from IFS, DODA and Synergi about events that have led to or potentially could have led to downtime and to reduce the probability for severe single downtime events to occur to be the best way to proceed.

10. References

CHAPMAN, F. M. & BROWN, R. L. 2009. Deepwater BOP Control Monitoring - Improving BOP Preventive MAintenance with Control Function Monitoring. *OTC,* 20059-MS.

DEW, L. L. & CHILDERS, M. A. 1989. MODU Drilling Rig Downtime: An Objective Analytical Approach. *SPE/IADC Drilling Conference.* New Orleans, Louisiana: SPE/IADC Drilling Conference.

DNV 2011a. DNV-OSS-101: Rules for classification of offshore drilling and support units. *In:* VERITAS, D. N. (ed.).

DNV 2011b. Forensic Examination of Deepwater Horizon Blowout Preventer. Det Norske Veritas.

KHELIFI, M. 1999. Downtime Reduction With Upated Maintenance System. *SPE,* 57559-MS.

MILITARY, U. S. 1984. MIL-STD-1629A: Proceudres for Perfomring a Failure Mode, Effects and Criticality Analysis. *In:* DEFENSE, D. O. (ed.).

MOUBRAY, J. 1997. *Reliability centered maintenance*, Industrial Press.

OGIDAN, B. & COETZER, C. 1993. Measuring Drilling Contractor`s Performance. *SPE,* 25685-MS.

PARETO, V. 1896. Course d`Èconomie Politique.

PTIL, PSA & NSHD 2002. Guidelines to regulations relating to material and information in the petroleum activities (The information duty regulations). *In:* NORWAY, P. S. A., AUTHORITY, N. P. C. & DIRECTORATE, N. S. A. H. (eds.).

SATTLER, J. & REED, B. 2004. Avoiding Drilling Equipment Downtime - Four Case Studies. *SPE,* 87957-MS.

SEADRILL. 2011a. Available: http://www.seadrill.com/modules/module_123/proxy.asp?C=42&I=2377%D=2&mid=179 [Accessed 01 May 2011].

SEADRILL. 2011b. Available: www.seadrill.com [Accessed 10 February 2011].

SEADRILL 2011c. Guideline - Downtime Reporting - Lessons Learned Transfer.

SEADRILL 2011d. SP-02-02 029_English.

SEADRILL 2011e. Synergy Downtime Report User Guide.

SKIPSFORSKNINGSINSTITUTT, N. 1983. SFI - Group System - A functional classification of drilling rigs. NFSI.

WOLTER, N., KACI, V., PITARD, G. & ANDERSEN, P. 2006. Preemptive Downtime Machinery Monitoring on Drilling Platforms. *SPE,* 102401-MS.

WWW.HOWSTUFFWORKS.COM 2011. Anatomy of an oil rig.

WWW.IFSWORLD.COM 2011. IFS.

WWW.OGJ.COM 2011. RamRig.

WWW.PETROLEUMONLINE.COM 2011. Mud Circulating System.

WWW.SLB.COM 2011. Diagram of Blowout Preventer.

11. Appendices

Appendix A – Corrective Actions reported in IFS

The following tables are made with data from the internal database IFS. The tables show the yearly amount of corrective actions reported in IFS for the different equipment groups from 2004 until 2010.

Rotary table, top drive and associated equipment

Year	Alpha	Epsilon	Venture	Navigator	Phoenix	Total	Average per rig
2004	30	82	32	19	0	163	40,8
2005	40	63	36	25	0	164	41
2006	71	51	11	30	0	163	40,8
2007	46	39	9	32	0	126	31,5
2008	63	48	13	25	5	154	30,8
2009	38	47	23	26	37	171	34,2
2010	32	47	20	34	49	182	36,4
Total	320	377	144	191	91	1123	36,5

Riser system incl choke, kill and booster lines

Year	Alpha	Epsilon	Venture	Navigator	Phoenix	Total	Average per rig
2004	19	0	16	49	0	84	21,0
2005	17	0	20	230	0	267	66,75
2006	26	2	13	65	0	106	26,5
2007	23	1	13	39	0	76	19
2008	23	0	8	33	3	67	13,4
2009	23	2	10	25	19	79	15,8
2010	16	1	11	8	15	51	10,2
Total	147	6	91	449	37	730	24,7

Blowout preventer control system

Year	Alpha	Epsilon	Venture	Navigator	Phoenix	Total	Average per rig
2004	17	17	13	135	0	182	45,5
2005	27	5	13	248	0	293	73,25
2006	42	14	11	67	0	134	33,5
2007	58	13	7	97	0	175	43,75
2008	65	7	14	192	5	283	56,6
2009	56	12	24	67	20	179	35,8
2010	28	11	18	16	20	93	18,6
Total	293	79	100	822	45	1339	43,9

Miscellaneous equipment for pipe/tubular handling

Year	Alpha	Epsilon	Venture	Navigator	Phoenix	Total	Average per rig
2004	9	2	2	103	0	116	29,0
2005	6	2	1	128	0	137	34,25
2006	7	0	0	124	0	131	32,8
2007	15	1	0	74	0	90	22,5
2008	9	1	0	86	1	97	19,4
2009	13	1	1	75	27	117	23,4

2010	7	2	0	42	24	75	15
Total	66	9	4	632	52	763	25,2

Drill floor tubular handling equipment

Year	Alpha	Epsilon	Venture	Navigator	Phoenix	Total	Average per rig
2004	9	14	56	41	0	120	30,0
2005	9	19	24	47	0	99	24,75
2006	12	18	37	26	0	93	23,3
2007	12	7	28	37	0	84	21
2008	17	20	28	39	0	104	20,8
2009	15	29	25	32	11	112	22,4
2010	17	19	14	44	17	111	22,2
Total	91	126	212	266	28	723	23,5

Drawworks & machinery

Year	Alpha	Epsilon	Venture	Navigator*	Phoenix	Total	Average per rig
2004	22	44	NA	NA	NA	66	33,0
2005	12	39	NA	NA	NA	51	25,5
2006	15	22	NA	NA	NA	37	18,5
2007	14	32	NA	NA	NA	46	23,0
2008	31	25	NA	NA	NA	56	28,0
2009	19	35	NA	NA	NA	54	27,0
2010	12	31	NA	NA	NA	43	21,5
Total	125	228	0	0	0	353	25,2

Derrick mounted vertical pipe handling system

Year	Alpha	Epsilon	Venture	Navigator	Phoenix	Total	Average per rig
2004	22	90	85	19	NA	216	54,0
2005	39	78	55	20	NA	192	48,0
2006	43	59	48	21	NA	171	42,8
2007	32	69	51	16	NA	168	42,0
2008	37	60	75	13	NA	185	46,3
2009	35	64	44	33	86	262	52,4
2010	31	57	40	8	100	236	47,2
Total	239	477	398	130	186	1430	47,5

Mud supply

Year	Alpha	Epsilon	Venture	Navigator	Phoenix	Total	Average per rig
2004	33	75	22	44	NA	174	43,5
2005	99	101	40	44	NA	284	71,0
2006	53	58	25	50	NA	186	46,5
2007	36	51	6	23	NA	116	29,0
2008	48	55	22	20	NA	145	36,3
2009	26	74	13	23	21	157	31,4
2010	30	55	5	30	28	148	29,6
Total	325	469	133	234	49	1210	41,0

Drilling control

	Alpha	Epsilon	Venture	Navigator	Phoenix	Total	Average per rig
2004	19	44	9	25	NA	97	24,3
2005	21	22	12	25	NA	80	20,0
2006	23	19	16	23	NA	81	20,3
2007	32	39	5	24	NA	100	25,0
2008	25	66	2	20	NA	113	28,3
2009	11	40	5	16	23	95	19,0
2010	6	42	5	10	31	94	18,8
Total	137	272	54	143	54	660	22,2

Overhead Cranes

Year	Alpha	Epsilon	Venture	Navigator	Phoenix	Total	Average per rig
2004	18	1	29	19	NA	67	16,8
2005	41	1	25	29	NA	96	24,0
2006	35	2	27	30	NA	94	23,5
2007	20	1	12	23	NA	56	14,0
2008	23	0	14	7	NA	44	11,0
2009	18	2	20	18	55	113	22,6
2010	7	0	19	12	26	64	12,8
Total	162	7	146	138	81	534	17,8

Choke and kill system incl. Mud/gas seperator

Year	Alpha	Epsilon	Venture	Navigator	Phoenix	Total	Average per rig
2004	9	27	2	8	NA	46	11,5
2005	21	9	3	18	NA	51	12,8
2006	10	5	2	10	NA	27	6,8
2007	11	16	2	31	NA	60	15,0
2008	21	17	5	23	NA	66	16,5
2009	11	18	5	9	13	56	11,2
2010	15	12	4	19	6	56	11,2
Total	98	104	23	118	19	362	12,1

Appendix B – Questionnaires

Interview onshore

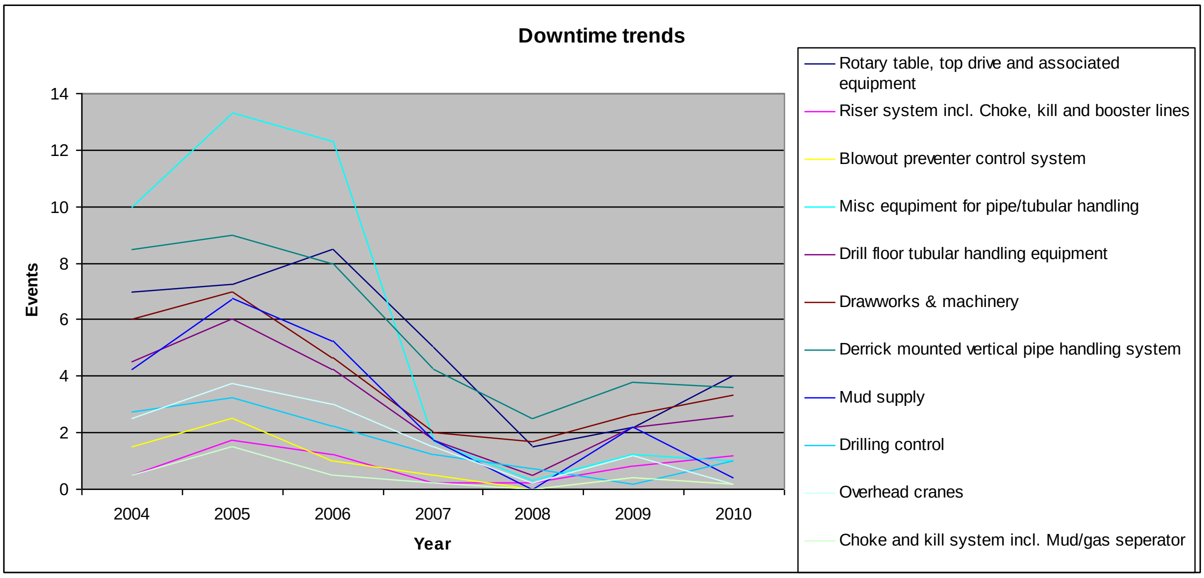

Figure 1: Downtime events reported in IFS

1: As one can see from Figure 1 there was a significant decrease in reported downtime events in IFS from 2006 to 2008. How can this decrease be explained?

2: How have Seadrill ensured that lessons learned on one rig with regards to maintenance are transferred to all relevant rigs? Please Explain

3: From your perspective; should a failure be classified and evaluated by the potential or occurred consequences?

4: What advantages and disadvantages would evaluating and classifying failures by its potential have?

5: What have been the biggest challenges improving offshore crews report quality?

6: How good is the communication between offshore and onshore personnel when it comes to report quality?

7: What feedback on report quality is given to the responsible parties?

8: How are IFS reports used by management for any statistics or in order to improve existing routines?

9: How does the onshore management make the value of having good report quality visible to the responsible offshore personnel?

10: What kind of studies have been done previously by Seadrill when it comes to maintenance optimization?

11: Have Seadrill ever considered having onshore personnel dedicated to ensuring the quality of reports in IFS?

12: What information would a ”perfect” corrective report in IFS contain from your perspective?

13: If you, without data, were to rank the causes off downtime from 1 to 6, where 1 is the one causing most, how would you rank them?

Causes of downtime	**Rank**
Poor design,	
Insufficient maintenance,	
Poor quality	
Poor planning	
Equipment operational limitations exceeded	
Lack of tools	
Lack of spare part	

14: How many percentage of the total downtime do you believe is maintenance related?

15: What are, in your opinion, the biggest challenges in order to reduce maintenance related downtime?

- How does Seadrill intend to overcome these challenges?
- What is the best way for Seadrill to overcome these challenges in your opinion?

Interview Offshore

1: Around 2006 we can observe a significant decrease in reported downtime events in IFS. What, in your opinion, might be the cause of this decrease?

2: How much are your internal maintenance routines influenced by lessons learned on other rigs?

3: How much of your working hours do you estimate you use on reports?

4: To what degree from 1 to 6 (where 6 is very much and 1 is not at all) do you feel that the amount of time you use on reports is worth it?

5: How satisfied are you with the feedback you get on the quality of your reports in IFS on a level from 1 to 6 where 1 is very little and 6 is very much?

6: How are the reports being used in order to improve maintenance routines in your experience?

7: Today all reports in IFS shall contain information on whether the failure have caused downtime or not. Do you regard this as important information?

8: How has the downtime information in IFS been of any use to you?

9: If a failure could have lead to downtime do you see any value in this being reported, despite it not actually leading to downtime this time?

10: If you, without data, were to rank the causes off downtime from 1 to 7, where 1 is the one causing most, how would you rank them?

Causes of downtime	**Rank**
Poor design,	
Insufficient maintenance,	
Poor quality	
Poor planning	
Equipment operational limitations exceeded	
Lack of tools	
Lack of spare part	

11: How much of the total downtime on your rig do you believe is caused by poor/insufficient maintenance? Please explain

12: What are, in your opinion, the biggest challenges in order to reduce maintenance related downtime?

13: What is the best way for Seadrill to overcome these challenges in your opinion?

14: How do you feel the new downtime reporting in Synergi affect your workload?

15: Do you feel that the Synergi reports are put to good use and worth the work load?

16: How do you feel onshore personnel can support you best in order to improve report quality?

17: Since you started working for Seadrill, what have been the biggest changes in the maintenance routines/philosophy?

18: What changes in maintenance do you regard as the most successful in order to reduce downtime?

19: Do you feel that your opinion and suggestions around the maintenance routines//philosophy are being considered to a satisfying degree?