Turnaround strategy development - a case study

Inge Lundhaug Berdahl

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Preface

This master thesis is written as a fulfillment of a five year master study at NTNU Department of Marine Systems. The workload of this thesis is 30 study points, or equal to one normed semester. The thesis is written for Statoils Research centre at Rotvoll Trondheim. The thesis has been written in the period from 18^{th} of January 2011 to the 28^{th} of June 2011 with guidance and supervision from Tom Anders Thorstensen from Statoil.

My direction of specialization is in marine operational technology and thesis main topic is within this field. The background for this thesis is that turnarounds and unplanned shutdowns are shown to be Statoils single most important cause of lost production for oil production offshore. Statoil is, in cooperation with IBM, developing a software tool for optimizing turnarounds. My task is to perform a case study of some scenarios simulated with this tool.

I wish to thank Tom Anders Thorstensen for the help and guidance he have provided during my work with this thesis.

Summary

Chapter 2 of this thesis handles the topic Maintenance Management and will establish a platform of word and abbreviations that will be used through the rest of the paper. Also maintenance theory of failure characteristics for an equipment will be explained.

The definition of lost production for offshore oil production platforms with an example of one of Statoils own platforms on the North Continental Shelf. Real data for production loss will be presented for a platform called Plant A.

In Chapter 4 the term Turnaround Management will be presented and some of the the state-of-art theory of the topic optimization of Turnaround Management will be given. Also projects initiated by Statoil to improve the management and execution of turnaround will be presented in this chapter.

Chapter 5 gives a qualitative presentation of a software program that is under development by Statoil for the scheduling and optimization of TARs for offshore oil production facilities. Some of the main elements of the software such as the objective, the model, the input and the output will be presented. The results of three different turnaround scenarios will be presented in Chapter 6.

The last part of the thesis, Chapter 7, will discuss the results and compare the results with real data .

Contents

List of Figures

List of acronyms

TAR Turnaround

PM Preventive Maintenance

CM Corrective Maintenance

NCS Norwegian Continental Shelf

PE Production Efficiency

CBM Condition Based Maintenance

MTTF Mean Time To Failure

PSAN Petroleum Safety Authority Norway

KPI Key Performance Indicators

CAPEX Capital Expences

PDF Possibility Density Function

Chapter 1

Introduction

Offshore oil productions facilities are producing oil and gas continuously 24 hours/7 days a week. The industry term of such a facility is a continuous production facility. Foreseen and un-foreseen incidents forcing a shutdown or a reduction of the production can occur. Planned shutdowns or Turnarounds (TARs) are normal activities on offshore installations and are used to perform necessary maintenance- and modification activities that requires a complete shutdown. On Statoil«s facilities on the NCS (Norwegian Continental Shelf) a typical TAR has a duration of 2 to 3 weeks and a typical frequency of one every second years. In addition unplanned shutdowns and reduced production which are caused by failure of one or more production-critical systems occurs. Offshore oil production facilities are capital intensive driven installations, which means that the cost of operations is high. Such operations produce continuously 24 hours 7 days a week. These two main factors explain why the downtime costs have such a huge impact on the bottom line for the company.

Before we go in depth on a maintenance strategy that optimizes a turnaround with respect to production efficiency, it is necessary to establish a framework of maintenance- and offshore terms. The next chapter will describe the basics of maintenance theory and develop a framework of terms. Abbreviations that will be used through this paper is explained as well.

Chapter 2

Maintenance Management

In this chapter I will go through the basics of maintenance theory and establish a framework that will be used troughout this thesis. Standards Norway (SN) - NS-EN13306 [6] have defined Maintenance Management as

> *"All activities of the management that determine the maintenance objectives, strategies, and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, improvement of methods in the organization including economical aspects."*

This definition says that the maintenance management is an integrated part of top management in an organization, and it includes all the activities that are aimed to determine the maintenance objectives, the strategy to fulfill these maintenance objectives and to assign those persons in the organization that are responsible that these activities are to be carried out successfully.

2.1 Types and categories of maintenance

Maintenance can be classified in different categories as illustrated in Figure 2.1 (Source: M. Rasmussen, Driftsteknikk GK, 2003 [1]) where the main categories are planned maintenance and unforeseen maintenance. When the maintenance is categorized as planned in this context it is the strategy we talk about. Generally it should exist a planned maintenance strategy for all the equipment failures in the system we looked at. In this ideal situation there will be no unforeseen failures in the system and for all the failures that can occur in the system there exists a planned maintenance strategy that re-set the systems state. This requires a sufficient knowledge of the system, the equipments and all the failure modes that an equipment can have.

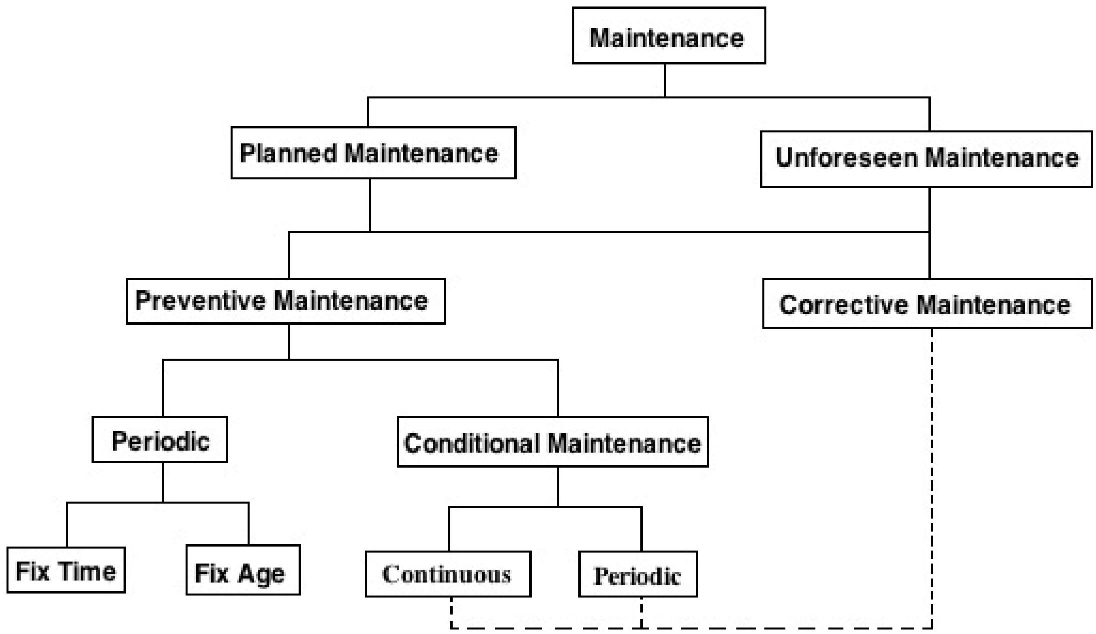

Figure 2.1: Types and categories of maintenance.

When we talk about planned maintenance we divide it between:

Preventive Maintenance This is maintenance that is aimed at preventing an equipment failure or to bring back the equipment from a deteriorated state to a state where it is as-good-as-new. Preventive maintenance is either done by periodic overhauling/replacement or by condition-based maintenance.

Corrective Maintenance This type of maintenance of an equipment is characterized by the fact that it runs till it fails. Corrective maintenance is used on equipment where it«s failure is not critical from an economical or safety point of view. It is defined as planned since it is a conscious choice to let the equipment run till it fails. The reason is that this is found to be a more cost efficient choice than periodic maintenance

Preventive maintenance is further divided between:

Periodic Overhauling/replacements This means that the equipment is periodically overhauled, either on-site or taken to a repair-site, or that it is replaced by a new one. The choice between these two actions is based on what is economically most beneficial. The period is either based on calendar-time or run-time.

Condition Based Maintenance (CBM) This is a a preventive maintenance process done with an inspection/monitoring of an equipment to determine its operational state. A reference state is used, normally the as-good-as-new, to determine the deviation. The monitoring can either be done periodically or continuously, depending of what is most efficiently and practically with regards to what technology is available and what is the most cost efficient method. If the equipments state is found to be unacceptable/below a chosen limit, a corrective maintenance action is triggered.

In Figure 2.1 there is a dashed line between the two ways of performing Condition Based Maintenance (continuously and periodically) and Corrective Maintenance, CBM is however defined as a Preventive Maintenance action. As mentioned above this is to mark that CBM is a preventive action and is used as a decision tool to decide whether a Corrective Maintenance action need to be triggered. An example of CBM is a monitoring system on a heat exchanger which consists of thermostats and flux meters. The values that are to be monitored are the temperature of both the cooling medium and the heating medium - in and out, and the flux (the amount of fluid that passes by a certain point) of both the cooling- and heating medium - in and out. This gives a total of 8 parameters to monitor. These parameters can again give the efficiency-parameter of the heat exchanger. If the operating efficiency-parameter drop below a given decision parameter, a corrective maintenance action is triggered. The reason for the deterioration of the heat exchanger could for example be that there is a leakage in the system, the system is overgrown or clogged.

As explained above there is a clear difference between the two categories of Preventive Maintenance when it comes to how they intervene with the equipment. While Periodic Overhauling/Replacement are done to maintain or better equipments state, Conditional Based Maintenance are done to gain information on the condition of the equipment to see whether maintenance is necessary. When deciding which type of maintenance to choose of a specific equipment it is then clearly necessary to know how and when the equipment fails, i.e. the failure characteristic of the equipment. This will be explained in the next chapter.

The production related availability of the equipments/system has an economical optimal point with regards to how much preventive maintenance is to be carried out. Both preventive and corrective maintenance generate costs, direct cost in form of man-hours, spare-parts, transport of personnel and spare-parts, indirect costs in form of downtime costs or lost production. Lost production is here defined as a cost, but more precisely it is a lost income. Either way it will have the same impact on the profit, so in this thesis lost production will be referred to as a cost, i.e. downtime cost. Generally the costs of performing a preventive maintenance action are less that what the case is for a corrective maintenance. For the direct cost (i.e. man-hours, spare-parts and transport of personnel and parts) it is clear that if you have enough time to plan the activity it can be done less expensive than a corrective activity. For the indirect cost (i.e. lost production/downtime cost) a corrective maintenance action will result in more downtime than a preventive action that can be planed in advance. Also for preventive maintenance activities it is ideal to perform these opportunistically, that is in a time period where the system or part of the system is down, for example during a turnaround. Later in the presented work this will be treated more thoroughly.

An important aspect of preventive and corrective maintenance activities is that increased volume of Preventive Maintenance will reduce both the direct cost (personnel, spare-parts, transport etc.) and the indirect cost (downtime cost) related to corrective maintenance. But increased volume of Preventive Maintenance will also generate direct and indirect costs. Figure 2.2 (Source: TMR4160 - Driftsteknikk GK, Course material, 2011 [2]) shows the cost of preventive maintenance (black) and corrective maintenance (green) and the combined cost/total cost as a function of its volume. The green graph shows the cost of corrective maintenance, the black graph shows the cost of preventive maintenance and the red graph shows the total maintenance cost as a function of the share between corrective and preventive. It must be emphasized that this a qualitative description.The important conclusion from this figure is that preventive maintenance cost increases and the corrective maintenance cost decreases as the volume of preventive maintenance activities increases. This shows dependency between these two types of maintenance activities and illustrates that there exists an optimal point where the total cost has a minimum. To find out what is the optimal maintenance strategy for each and every component in a system it is necessary to know the failure characteristics of the components.

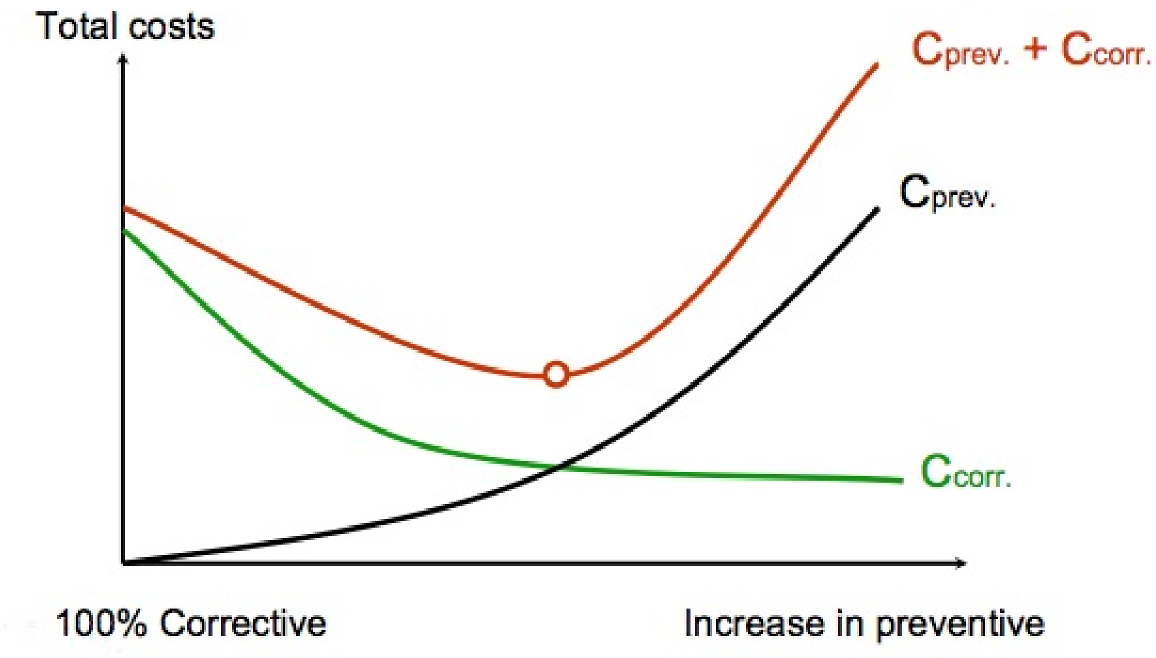

Figure 2.2: Maintenance costs.

2.2 Failure Characteristics

To decide which maintenance strategy to choose for an equipment it is necessary to know it«s failure characteristics, that is it«s failure modes and the related probability for failure for every failure mode. This means that an equipment can have several failure modes with different probability for failure. This can for example be illustrated by an axial gas compressor that is shown in Figure 2.3 (Source: [3]). This is a mechanical device that compresses a gas.

Figure 2.3: Picture of an open axial gas compressor.

Its main components that are subject to failure are the mechanical moving/rotating components and the components that are directly connected to those. These are the shaft, the airfoils and the shafts bearings. In this way we can come up with three failure modes for this compressor, namely failure of the shaft (cracks or bended), failure of the airfoils (broken of or twisted) and failure of the bearings (crushed wheels). Each of these three failure modes for the compressor can have different possibilities of occurrence.

A failure distribution for a failure mode of an equipment is a mathematical model that describes the probability of the failure occurring over time. This is also known as the probability density function (*pdf*), and all other functions commonly used in reliability engineering can be derived from the *pdf*, such as the *reliability function*, the *failure rate function* and the Mean Time To Failure ($MTTF$). Let $f(t)$ be such a failure distribution function for an equipment, where t denote the equipments life time. Let a and b be given times where $a < b$, then the possibility for the equipment to fail in the time interval $[a, b]$ are given by

$$\int_a^b f(t)\ \mathrm{d}t\ ,\ \text{where} \int_0^\infty f(t)\ \mathrm{d}t = 1$$

The reliability function $R(t)$ that gives the possibility for an equipment *not* to fail in the time interval $[0, t]$ is given by

$$R(t) = \int_t^\infty f(x)\ \mathrm{d}x$$

The failure rate function $z(t)$ that gives the instantaneous failure rate, that is failures per time unit (e.g. x failures per month) is given by

$$z(t) = \frac{f(t)}{R(t)}$$

The $MTTF$ is given by

$$MTTF = \int_0^\infty t f(t)\ \mathrm{d}t$$

M. Rasmussen [1] describes three main failure patterns. In addition to these three there are one more that is a combination of two of these. The $f(t)$ and $z(t)$ of these four main patterns are illustrated in Figure 2.4.

Equipments that having "Running-in" failure characteristic have a higher probability to fail in the beginning of its lifetime and the probability for failure will decrease over time. Many electronic equipments and components are shown to have this failure characteristic. For equipment with this type of failure, replacements/overhauling that re-set

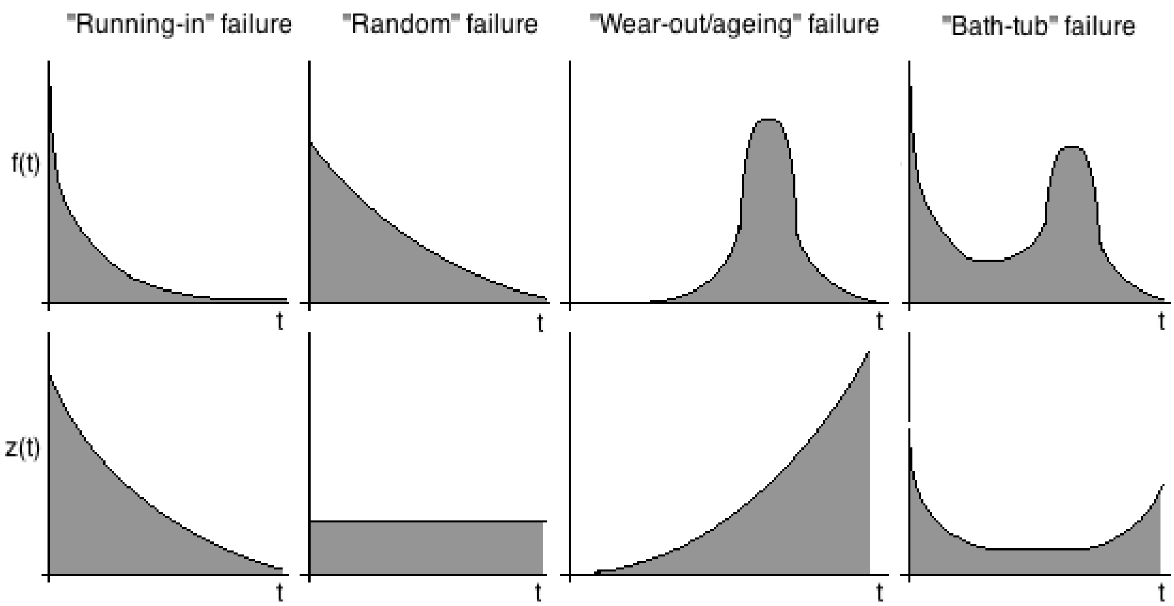

Figure 2.4: Four different types of failure patterns.

the equipments state, will reduce its reliability. Equipment that has "Random failure" characteristic fails randomly, as can be seen with a constant failure rate. Equipment with "Wear-out/aging failure" characteristic has a concentrated probability density around a specific operational age, as the $f(t)$ graph shows. "Wear-out/aging failure" characteristic is typical for equipment and systems that are directly in contact with process a medium (oil, water, fuel-gas etc.), for rotating equipment and where corrosion and material fatigue is present.

Periodically maintenance with overhauling/replacement are suitable only for those equipments showing a failure characteristic of a "Wear-out/aging failure". If the *pdf* have such a distribution, that is a minimal distribution around the mean value, then the maintenance interval can easily be determine with a low degree of uncertainty. For equipment with higher variation around the mean value it is more difficult to determine such a maintenance interval. Therefor the equipment that is most ideal for periodic maintenance are those that have a known *pdf*, and where the failure distribution has a sufficiently concentration around the main value.

For equipment that have a "Running-in failure" characteristic maintenance will only decrease the equipments reliability. The reason is that the probability for failure are decreasing with a relatively high probability when the equipment is recently overhauled/replaced.

This means that corrective maintenance is the optimal strategy with respect to reliability for equipments with this kind of *pdf*.

Also for equipments with a "Random failure" characteristic periodic maintenance has no impact on the reliability because the probability for failure are constant with time. This means that the optimal strategy with respect to reliability for equipments with this kind of *pdf* is corrective maintenance.

If there exist a suitable and cost efficient Conditional Based Maintenance available, equipment with "Random failure" characteristics is most suited for this strategy. With Conditional Based Maintenance for an equipment, maintenance is only done when it is necessary.

The main problem by applying a maintenance strategy for an equipment is that either the failure characteristics for its failure modes are unknown, or that in best case just the MTTF is given by the supplier. One of the reasons of insufficient information by the supplier for the failure characteristic is that for many industrial components the failure characteristics are highly dependent on what load the equipment is operating under. Another reason is that for an equipment that have an excepted lifetime of for example 10-20 years, it is difficult to gather data that can contribute to the establishment of a failure distribution. The simple reason for this is because the supplier modifies the equipment frequently, thereby no such information is obtainable.

2.3 Improved Maintenance Management

The Management Loop for Maintenance is a management model developed by PSAN (Petroleum Safety Authority Norway) and the oil industry, mainly by Statoil. The model is presented in Figure 2.5 (Source: Petroleum Safety Authority Norway webpage, [4]). Management of safety/regularity/cost related maintenance is in the model presented as a continuous process (loop), that, with the input of resources in form of the organization, materials and support documentation, produces products in form of safety (low risk), regularity/availability and maintenance cost. Each element in the loop can consist of different work processes with a related product that is a necessary input for the next element in the loop. Supervision of all the elements/work processes is also implemented.

The purpose of the first element in the loop, "Goal and requirements", is to covert the

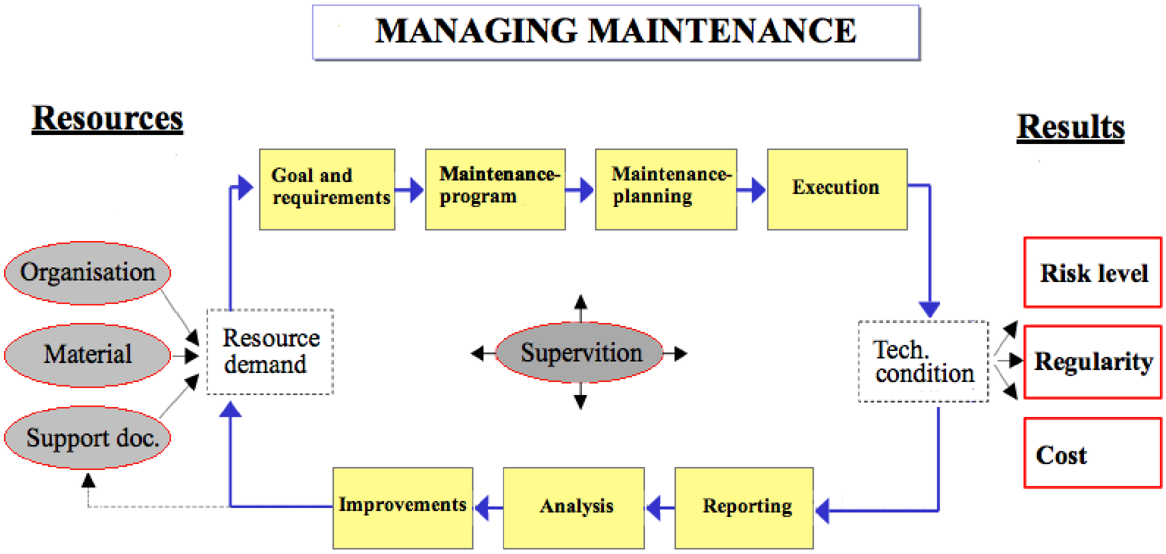

Figure 2.5: Maintenance Management loop developed standardized by PSAN.

companys own safety goals and the authorities requirements regarding safety to maintenance related goals and requirements, and also to develop KPI (Key Performance Indicators). KPIs are used by management for supervising and to control that the goals and requirements are reached.

The purpose of the second element, "Maintenance program", is to establish/improve the maintenance program that can meet the goal and requirements. This program includes a general preventive maintenance program, inspection program, program for condition monitoring and testing of all the systems, and equipments in the installation(s). The equipments failure characteristics is an important input here to establish a best as possible maintenance program. This is tailor made for each an every equipment in the installation.

The third element "Maintenance Planning" has the purpose to generate maintenance activities resulting from the maintenance program, and to schedule these. The scheduling of these maintenance activities has a horizon of 10 years, 1-2 years and day-to-day basis depending on the degree of details. We will return to this scheduling horizon in 3.1, where it will be explained what type of scheduling are done in what perspective.

The purpose of the forth element "Execution" is to execute the established maintenance activities in the previous element. This includes carrying out the preventive and corrective maintenance activities, control and finalization/afterwork of the activities. Logging equipments history is also a process carried out here.

The resources (organization, material and support documentation) are feed into the "production line" consisting of the mentioned four elements. This results in a risk level for the installation, a level of availability of the installation (and a conjugate downtime of the installation) and a maintenance cost for the installation.

The three elements at the bottom of the loop after the result are "Reporting", "Analyzing" and "Improvements". These are stages that are meant to create work processes to improve the previous result. The purpose of the element "Reporting", is to gather, quality assure and distribute detailed information of the results. The information should include KPIs that are informative and cover all the important aspects of the work processes that lead up to the previous result. It is important that this reporting reaches all the part of the organization that are involved in the maintenance management. Failure history for the equipment is an essential part of this reporting, and is necessary to develop and to improve the knowledge of the failure characteristic for the equipment. The next element in line is "Analyze". In this context this means analyzing and processing the data logged from the previous improvement round. The last element is "Improvements". This element focuses on work processes that initiate, execute and follow-up improvements actions based on previous analysis, experience transfer etc. Also if the type of/quality of or the amount of resources that are feed into the work process loop need to be changed this last element in the loop is meant to initiate such.

As explained, this is a model that creates a framework meant to continuously improve the the work processes for the maintenance management of an installation.

2.4 Maintenance activities

The different equipments on a platform generates a set of activities that need to be carried out in order to maintain the level of safety and availability required. This could be maintenance activities, inspections/surveys, modifications and tie-ins of new equipment. These activities can be divided between planned activities and unforeseen activities. Activities that can be categorized as planned are preventive maintenance, modification/tie-in of new equipment, inspections/surveys by authorities etc., in other words all the activities that can be planned and scheduled. Activities that are categorized as unforeseen are corrective maintenance on equipment that fails and need to be fixed/replaced. Since a platform produces oil continuously all around the clock, some of these activities will require a partly or a total shut-down of the production in order to be carried out. So in order to carry out a certain amount of these necessary activities, it is a need to shut down the production for a certain time. In the offshore oil industry it is a normal practice to carry out such a shutdown on a regularly basis. This explains the need for TARs.

Chapter 3

Lost production

This chapter will first explain Statoils activity on the Norwegian Continental Shelf with regard to their oil production. We illustrate this with an example which quantify the oil production loss for one of Statoils platforms. Then further investigation of what causes this lost production will be explained. Statoil has a standardized way of categorizing the different types of losses and these categories will be presented. At the end of the this chapter the production loss for a platform will be presented. This will later be used when comparing real results with the ones received from the TAR Analyzer.

3.1 Statoils oil and gas production on the Norwegian Continental Shelf

Statoil is an integrated technology-based international energy company primarily focusing on upstream oil and gas operations. Statoil is the worlds 3rd largest vendor of crude oil, and the company supplies 14% of the gas consumed in the European market. Statoil - E & P Norway (Exploration & Production Norway) currently operates 39 offshore facilities and 6 onshore facilities located in Norwegian waters and onshore. Statoil«s equity production on the NCS in 2008 was a total of 1.90 million barrels of oil equivalents per day (mboed) and in 2009 was a total of 1.45 mboed. But this production volume could have been higher with higher PE (Production Efficiency). Figure 3.1(Source: Inge L. Berdahl, Pre-work for this Master thesis, 2010 [5]) illustrates what was the theoretical production potential of oil and what was the actual production of oil from 2007 to 2009 for one of Statoil«s production installations on NCS.

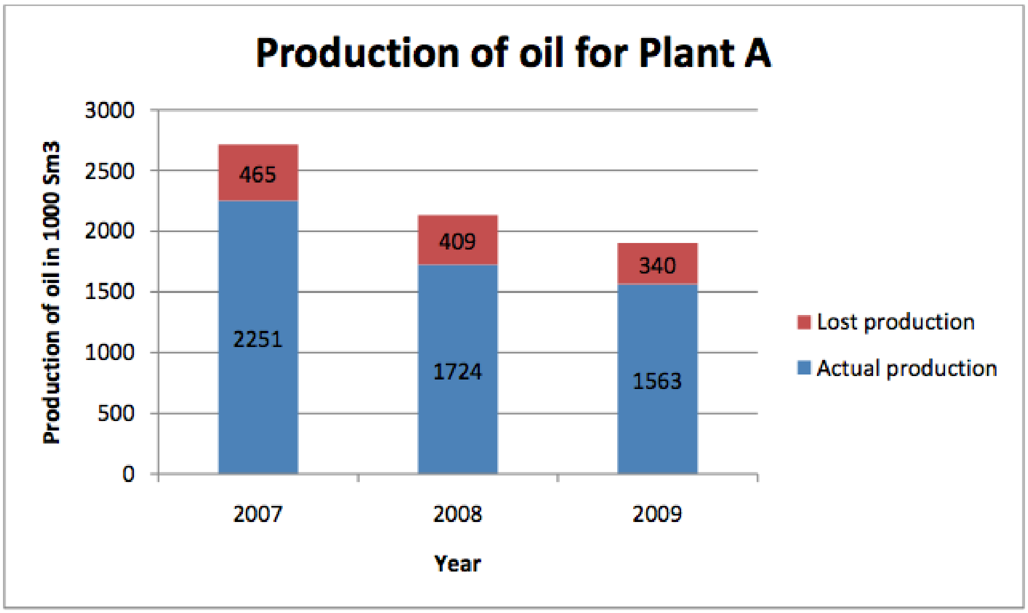

Figure 3.1: Actual production and the loss for Plant A from 2007 to 2009.

A common way of measuring production is to simply measure the production of oil alone since the gas is seen as the by-product. In some areas of the world all the gas is burned up with a flare on the platform as it comes up with the oil from the reservoir. On the NCS the gas is either used for re-injection down into the reservoir to increase the pressure or, if the infrastructure permits it, it is transported to shore for sale. But in both cases, the production and the production loss is generally measured by the production of oil.

Due to confidentiality the installation given as an example in Figure 3.1 is referred to as Plant A. The need for confidentiality is necessary because PE information can be used by externals in a way that have a negative impact on Statoils business. The PE information could for example be used to speculate in future stock prices and also give customers and suppliers an advantage when negotiating future contracts with Statoil.

As can be seen from Figure 3.1, Plant A had a theoretical potential of 20-24% higher annual production of oil between 2007 and 2009. Even a small increase in production efficiency will present a high increase in the production volume and thus the platforms profit. The insentive to increase the production efficiency is naturally high with these enormous volumes of lost production.

3.2 The most important cause of lost production

TARs and unplanned shutdowns are Statoil«s single most important cause of lost production. This make management of turnarounds and unplanned shutdowns an essential part of Statoil«s strategy for an efficient operation of assets and plants.

In addition to the TARs that are planned shutdowns, unplanned shutdowns occur. The reasons for these shutdowns can be many, and from the platforms perspective it can be both internal and external causes. Internal causes are mainly due to failure of some of the platforms critical equipment that forces a shutdown before the next TAR. External causes can be hard weather or shutdowns of a interdependent platform.

There exist what we call interdependencies between some of the facilities on the NCS. This means that a shutdown on one platform can force a shutdown or reduced production on a dependent platform and visa versa. This makes the scenario for deciding the expected lost production for a single platform more complex. Take Plant A as an example. The oil and gas comes up from wells placed on the sea bottom located underneath the platform and a separate field 10 kilometers north from the plant. From these wells the oil and gas are transported up to the platform to be processed. Then the oil is transported to another platform for storage and export. For example if the storage/export platform for some reason cannot receive the oil from Plant A, then Plant A has to reduce or shutdown it«s production.

3.3 Definition of lost production

There is a need to define what is meant by lost production of oil and gas for an installation. The actual production from day to day can easily be monitored, but in order to measure what the lost production is on a daily basis it is necessary to set a daily potential production target (theoretical production potential). Naturally the lost production for one day is then defined as the difference between the potential production and the actual production. The potential production rate at a time (production volume per time unit) can simply be described as whatever is less of

- Delivery rate from reservoir
- Passing rate through subsea equipment
- Processing rate on the platform
- Export rate/storage capacity

Each of these stages in the upstream process stages of oil and gas can be a bottleneck for the actual production on an offshore platform.

3.4 Production loss categories

In order to reduce the production loss it is necessary to know what the causes for the losses are. If it is possible to address the loss to a specific equipment or activity in the production line, then effort and resources can be pin pointed so that the bottlenecks can be identified and cleared in order to have a stable production. But upstream production of oil and gas offshore is a complicated process that involves a lot of equipments that form different system, and the systems have dependencies between each other. In addition a platform can have interdependencies with other platforms that affect its PE. External physical and governmental factors can also affect a platforms PE. A standardized way of categorizing the different sources for loss is needed.

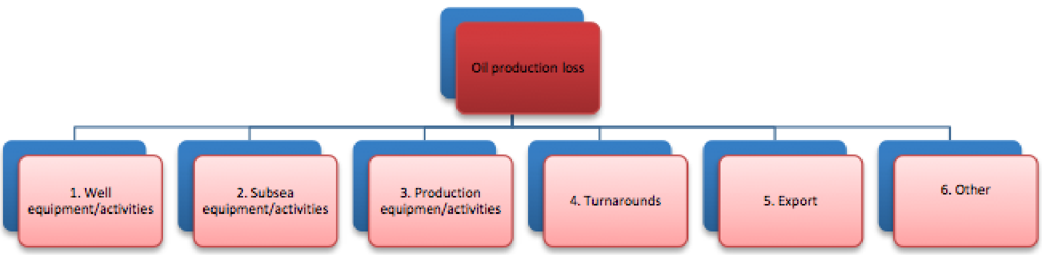

Figure 3.2: Statoils six categorize for lost production.

Statoil has a standardized way of categorizing these losses, where there are six main groups of lost production. Figure 3.2 shows these groups. As can be seen from the figure the three first groups are losses caused by activities/equipment located on the well(s), from the seabed up to the deck of the platform and on the platform, respectively. Group number four is losses due to TARs that require the production to be shut down. Group number five is losses due to limitation on the export line for the processed oil and gas. Group six is losses due to other causes that is not covered in the previous groups for example weather problems, strike/lock-out etc.

Under each of these groups there are 6-7 sub-categories, a total of 33, where the causes are addressed in more detail. A complete table of all the groups and their sub-categories with explanation can be found in the Appendix. Within these sub-categorize it should be possible to place each quantity of lost production that differentiates from the daily targeted potential production.

In addition to dividing the losses between these 33 sub-categories presented, there are several other ways to divide the losses. For example:

- Between planned and unplanned shutdowns
- Between specific system or equipment (for example a riser, the flare, a compressor etc.)
- Between specific types of equipments (for example static equipments, rotating equipments etc.)

3.5 Production losses for Plant A between 2007 and 2009

In the pre-work for this thesis [5], the production losses for Plant A was investigated. Each of Statoils production platforms reports the daily production. This report contains the daily production, the daily production loss and which categories every loss falls under. So for one day, the total daily loss can fall under several different categories. In [5] the author looked at the production loss from 2008 to 2010.

Figure 3.3 shows the production loss distribution between the main categorize 1- 6 for Plant A during the period from 1^{th} June 2008 to 1^{th} of November 2010, a total of 29 months. The total volume of lost oil production during this period was reported to be

790.000 Sm3, and the total production of oil during this period was 3.650.000 Sm3 or 30 million barrels of oil. This means that the potential production of oil during this period was 4.400.000 Sm3 and the production efficiency was approximately 83 percent.

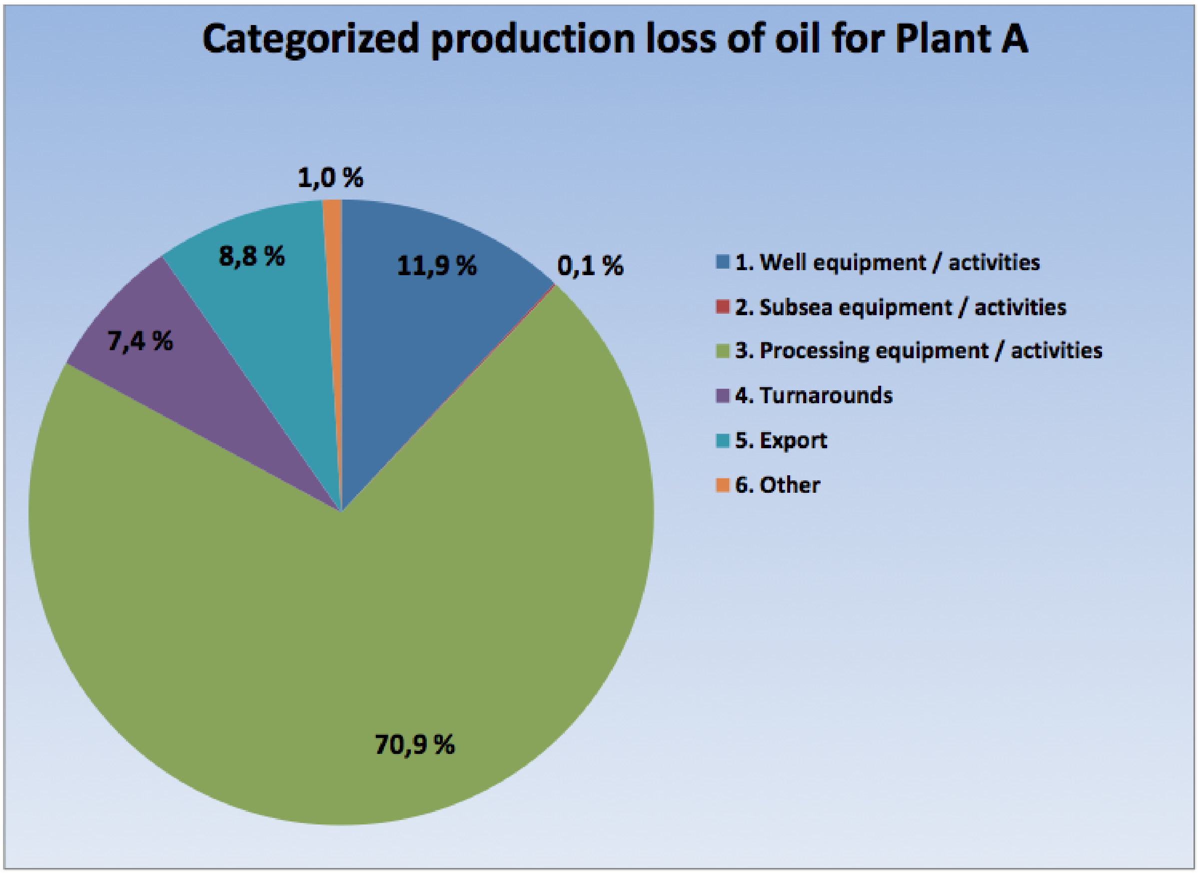

Figure 3.3: Categorized production loss in percentage for Plant A.

As can be seen from the chart in Figure 3.3 the main losses are category 1 (Well equipment/activities), 3 (Processing equipment), 4 (Turnarounds) and 5 (Export), with category 3 as the absolute largest with 71 percent. These four categories together make up 99 percent of the total loss during this period. Loss category 2 (Subsea equipment/activities) and 6 (Other) presents a negligible loss of 1 percent.

As mentioned, the six main loss categorize in Figure 3.3 has 33 sub-categorize. If we look at the losses divided on these 33 sub-categorize, 5 of these represents 73.5 percent of the total loss. Also, 21 of the sub-categories represented under 4 percent each of the total loss during the period of 29 months. As can be seen in the listing below, the largest contributors to loss are equipment failure and activities connected to processing equipment onboard the platform. The five largest contributors to lost oil production were:

1. (3.4) Equipment failure and unplanned activities on processing equipment - 27.8 percent
2. (3.1) Planned activities on processing equipment - 18.7 percent
3. (3.6) Modification projects on processing equipment - 12.0 percent
4. (3.5) Leak of competence and misaction on processing equipment - 7.7 percent
5. (1.4) Equipment failure and unplanned activities on well equipment - 7.2 percent

As can be seen the sub-category that represent the largest share of the oil production loss is 3.4 - Equipment failure and unplanned activities on processing equipment. From the five sub-categorize listed above 2 and 3 represent losses due to planned activities scheduled during TARs, and 1 and 5 represent losses due to unplanned shutdowns/reduced production. Reduced production is caused by partly malfunction of the processing system due to deteriorated or failed equipments.

To compare the real data with the achieved data from TAR Analyzer it is necessary to exclude some of the loss categorize. The sub-categorize for losses that are implemented in the TAR Analyzer are:

- 3.1: Planned activities on processing equipment - 18.7 %
- 3.4: Equipment failure and unplanned shutdowns on processing equipment - 27.8 %
- 3.6: Modification projects on processing equipment - 12.0 %
- 4.1: Planned shutdowns/TARs - 5.8 %

Implementation for including losses from category 5 is under development, that is losses due to interdependencies with other installations. The TAR scenarios that will be presented in Chapter 6 will not include this feature, so therefore the data from the real losses here will not include loss from category 5. The four sub-categorize listed above represent 64.3 percent of the total oil production loss for Plant A. As mentioned earlier in this section, sub-category 3.1, 3.6 and 4.1 is regarded as planned losses that occur during a TAR. Sub-category 3.4 is regarded as unplanned losses that is either caused by an unplanned shutdown or reduced production. Figure 3.4 shows the proportion of these two categories of the loss that are comparable with the results from the model in Chapter 6 and listed above. As can be seen the planned losses contribute to 56.8 percent and unplanned shutdowns and reduced production contributes to 43.2 percent.

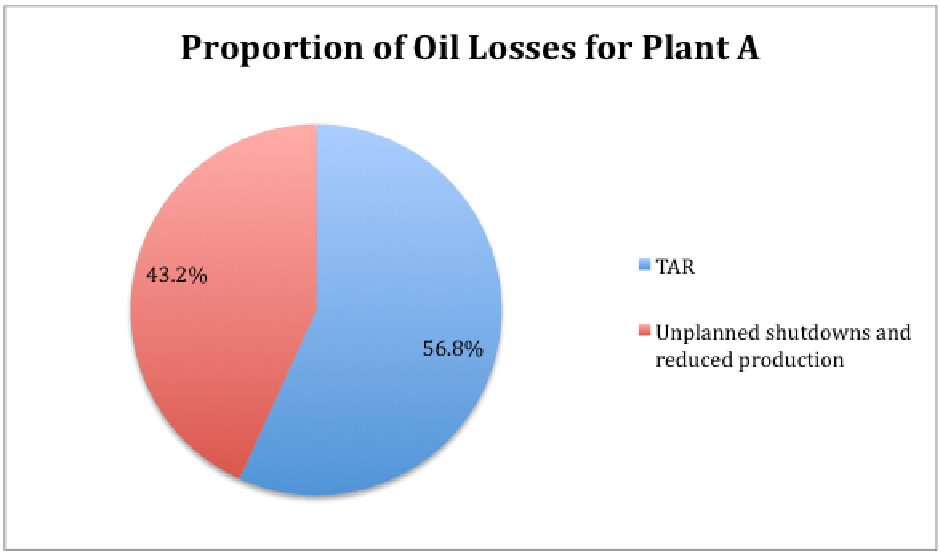

Figure 3.4: Proportion between planned and unplanned losses for Plant A.

Chapter 4

Turnaround Management

For large scale assets there will be necessary activities which can only be carried out when the plant has been taken off line, and made safe and available. Such activities can be preventive and corrective maintenance, inspections, modification projects and expansion of the asset. Assets in offshore oil industry are previously given as an example where TAR is common practice, but this is not the only industry where this is the case. For almost all production facilities that produces on a continuous basis TAR is utilized. Examples of industries that also have a culture for conducting TARs are chemical industries, petrochemical industries, paper mills, metallurgy industries etc, in other words all production industries that produces all around the clock.

As mentioned earlier, TARs and unplanned shutdowns have a significant impact on Statoils production on the NCS. The conducting of TARs and the decision that these TARs should be carried out on a regularly basis were utilized ever since the first platform started its production in 1972. The reason was that the platforms were designed to produce on a continuous basis and that, as mentioned previously, there were some activities that required a shutdown of the production in order to be carried out. However, time interval between each TAR and the duration for these were more or less a practical choice there and then. These intervals and duration have been utilized up to now, and it is only in the recent years Statoil has started asking question whether the chosen interval and duration for a TAR for a certain platform is the most optimal one with respect to the overall production of oil. Thus the projects, with the objective to reduce production loss through optimization of TARs, as mentioned in the last section of this chapter have been initiated.

Reliability for a continuous production plant should be the fundamental driver. In order to be profitable, a company needs consistent means of production delivered by reliable operating plant. Lost production that is caused by shutdowns will have a direct impact on the bottom line. Thus the management of TARs is not only a isolated affair for the Maintenance Management, but concerns the top management in the company.

4.1 Three planning perspectives of TARs

As shown in Figure 4.1 the planning perspective for TARs can be split in three time scales for strategy, planning and the execution. The first phase which is called "Overall Strategy for TAR" focuses on a time frame of approximately 10 years or more. To put this view in a perspective, we use Statoils TAR Management as an example. Statoils schedule the TARs for a platform on a 10 year perspective. This involves the decision on how many TARs to be conducted during this time horizon (time interval between each TAR) and the duration for each. Also outlined in this phase are those modification projects that can be foreseen to be undertaken during this time horizon.

1 Overall Strategy for TARs	2 Planning of a TAR	3 Execution of a TAR
- Frequency - Duration - Modification Projects	- Planning of the activities to execute - Allocation of resources - Dividing the total TAR time between planned- and corrective activities	- Supervision of undergoing activities - Handling unforeseen incidents
10 years perspective	12-15 months perspective	0-3 weeks perspective

Figure 4.1: Planning perspectives for TAR Management.

The next phase, which is called "Planning of a TAR", focuses on a time frame of approximately 12-15 months and handles the planning of one single TAR. This phase handles the prioritized and scheduled activities in the forthcoming TAR, the execution order and which activities that can be done in parallel. A Gantt chart is established for this purpose. It is here important to get an overview of the resources that are needed for each activity for the forthcoming TAR, and the planning of gathering these resources. Also the allocation of time for carrying out corrective maintenance need to be decided.

The last phase, which is called "Execution of a TAR", has a time frame that lasts from the shutdown is a fact until the production is started again. Processes here are the execution of activities and managing of on-going activities. Also documentation, reporting and status updates of the activities are work processes that are carried out in this phase.

An important aspect with TAR Management, that can be explained by these perspectives, is the cost and lost income that the TARs generates. There are different ways of calculating the cost that a TAR represent, depending on which time perspective is chosen. By cost we here mean both direct and indirect cost. The direct cost here are as mentioned in Chapter 2.1, the planning, cost of material, man-hours, transport etc. i.e. cost that are directly linked up to the TAR. The indirect cost are downtime cost for shutting down the production. What is meant by the cost by looking with different perspectives is that both the direct and indirect cost will be higher over a given time horizon if the volume of TARs is increased. The volume TAR means the total time used for TARs during a time period. For example if a TAR is conducted every second year, then the yearly profit will reflect this with a reduction every second year because income from the yearly production will be reduced (indirect cost due to shutdown) and the cost will be higher every second year(direct cost linked to the TAR). This way of accounting could be misleading and the cost linked to a TAR should in this example be distributed over two years instead of one. Another question is what we gain in production by carrying out the TAR, in other words, what would the production volume have been if the TAR had been carried out every forth year instead of every second year. In other words it is difficult to give an accurate measurement of the economical impact of conducting TARs.

4.2 Literature review on TAR Management

Most of the literature on the subject on TAR focus mainly on the two last phases of TAR Management defined in Figure 4.1, more precisely on the planning phase 1-2 years before the execution of a TAR and until its over. The reason for this can be explained by the fact that when TAR (also known as Outages and Shutdowns) was introduced as a technical term in maintenance literature, the production assets were assembled with less components and these components were less complex than what is the case to day. This implied that there were fewer activities that needed to be carried out during a shutdown. There were also less requirements by the Authorities than today. This implied less inspections and certifications. In the recent decades the production systems have been larger and more complex, and there are also more requirements and regulation by the Authorities, which makes it necessary to carry out more maintenance activities, modification activities and inspections activities.

For example in the book Managing Shutdowns, Turnarounds and Outages by Brown [7] the focus is on identifying-, planning-, scheduling- and executing the work that need to be done in a TAR. The author briefly mentions that the prioritizing of work (read activities) need to be carefully viewed. So in other words this book focuses on the phase 2 and 3 in Figure 4.1. Another example of literature that focuses on these last phases is the book Managing Maintenance Shutdowns and Outages by Levitt [8], but here the author focuses even more on the execution phase. Both of these examples of literatures on the subject TAR Management have little or no focus on an overall objective on maximizing the production efficiency over a relatively long time horizon. They do not address the important question whether the interval between the TAR can be prolonged and what kind of impact this has on the overall production efficiency. Both books were written and published in 2004.

In contradiction to these two examples in "Turnaround, Shutdown and Outage Management" by Lenahan [9] from 2006, all the three phases in Figure 4.1 are included. Lenahan raises the fundamental and important question "Is the TAR necessary at all?". To quote Lenahan:

> *"Every maintenance task carried out costs money that is subtracted from the bottom line, the profit margin. At the front end of the business, disciplines such as procurement, production planning, sales and marketing are being honed to a fine edge by use of latest technology, massive management input and constant re-evaluation, while at the back end disciplines such as maintenance (and especially TAR Management) have undergone, in many companies, little more than cosmetic change in the past thirty years. "*

In the last part of the book Lenahan gives an example of a real case for a fuel and lubricant production company called SASOL, where the frequency of conducting TARs, the duration of each TAR and a prioritizing of maintenance activities are dealt with in order to maximize the production over a given time horizon. A software program named APT [9] was used to schedule and optimize the mentioned parameters. The interval between the TARs was prolonged from every second year to every forth year. In addition they performed a criticality analysis of those equipments in the production system that were the main drivers for production loss and maintenance during a TAR. The project resulted in a positive increase in production.

It should be mentioned here that there exist little literature that addresses the first phase defined in Figure 4.1.

4.3 Project initiated by Statoil to increase Production Efficiency

4.3.1 RAPID

RAPID (Remove Activities, Prolong Intervals and Decrease Duration) was a project initiated in 2003 by Statoil in collaboration with SINTEF/MARINTEK. The project was focusing on how to increase production and reduce operational and maintenance cost through better execution of TARs. As the project name indicates, the way to reach this objective was to:

Remove Activities As mentioned in 2.5 "Maintenance Activities" a TAR is necessary to carry out activities that requires a shutdown. Removing such activities reduces the scope of the turnaround and opens the possibility of shorter turnarounds. Some of the solutions/results where to:

- Systematic approach when defining the scope of work for a TAR. The use of SAP is an important aspect of this approach, since this program can give a overview of all the necessary activities that need to be carried out. SAP is a software program used by Statoil that among other things generate work orders that need to be carried out and where all processes connected to material logistic are logged and initiated.
- Better utilization of unplanned shutdowns. When an unforeseen shutdown occurs the managers have only a short time to respond. Traditionally, quick return

to full production is stressed and opportunistic maintenance is only included if time and resources allows such. The idea is to challenge the existing mindset by extending the shutdown period of such unforeseen shutdown to perform additional activities that require a shutdown and that are scheduled for the next TAR, if this can be shown to be cost efficient. In this way the duration of the next TAR can be reduced, and the production could be increased. This requires that all activities are well documented, prepared and known by the involved parties.

- Some activities that requires a complete or partial shutdown can be improved such that no shutdown is required. For example methodologies for inspection activities/surveys that are capable of verifying the technical condition of process equipment without having to open it. Also the development of improved or new methods to perform "hot work" during operation - surveying Òhot workÓ technology, e.g. welding habitats, hot tapping, various methods of cold cutting/grinding etc.

Prolong Intervals In order to be able to prolong the intervals between the TARs it is essential to have condition monitoring of the equipments. Since one important component of the maintenance performed during a turnaround is mechanical condition assessment, there is a need for better, more widespread use of condition monitoring. This aspect also includes mapping methods for temporary repair of minor faults in pipework with a view to make it last until the next repair opportunity.

Decrease Duration The duration of a turnaround offshore is normally determined by a few critical jobs. Some of the solutions/results provided to decrease the duration for a TAR is a methodology to challenge critical jobs. By restructuring the tasks and improve maintainability it is possible to cut down the duration considerably. Also the mapping of Cleaning In Place (CIP) technology - many larger tasks are related to tanks and pressure vessels and involve cleaning. Utilizing and preparing for the use of CIP technology offers a potential considerable time saving.

4.3.2 Optimization projects for TAR

In 2006, Statoil and IBM launched a project to develop business processes and decision support tools supporting Statoils initiatives for the improvement of the company TAR performance. A total of three specific projects were initiated:

- Improve turnaround and shutdown preparedness and performance
- Optimize TAR and unforeseen shutdown frequency and duration for a single platform
- Optimize TAR and unforeseen shutdown frequency and duration across interdependent platforms

The main objective for the first project is to perform an efficient management of ongoing TARs and shutdowns. This involves monitoring of those activities that are to be carried out with the related resources required (man-hours, material, part of system required to be shutdown etc.), and the performance of ongoing activities. The objective for the two last projects (which in reality are merge meaning that the last one is an extension of the first one) is the development of a software program that optimize the scheduling of activities for TARs over a certain horizon with the objective to maximize the overall production. This software program is called Risk Analyzer and will be explained in the next chapter.

4.4 Shutdowns and TAR utilization

In order to conduct mechanical repair of the processing equipment it is necessary that (1) the production is shut down, (2) that remaining gas in pipes, compressors, heat exchangers and other areas in the processing system that can contain gas is released and (3) the system is injected with nitrogen gas so that the oxygen level in the system is under a certain level. As well known there are three elements that need to be present in order for a fire/explosion to occur: oxygen, heat and flammable substance. Figure 4.2 [10] shows a shutdown profile.

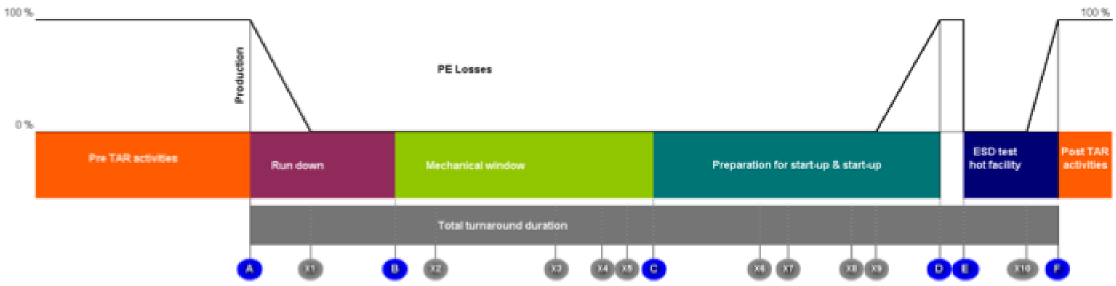

Figure 4.2: A shutdown profile consisting of six phases.

As can be seen in the figure there are five phases (the Emergency Shut Down test phase is not dealt with here). The first phase is the Pre TAR phase, which is the phase before the TAR starts. In this phase the production is at 100 percent. The next phase is the run-down phase, which involves gas release and nitrogen gas injection. In this phase the production is gradually shut down. The third phase at zero production is the mechanical window. This is the phase were maintenance activities that requires a mechanical window can be performed. The fourth phase is the preparation for start-up, and in this phase the production is gradually increased up to full production. And the last phase is the post TAR phase.

The Run-down phase takes approximately 48 hours and the Start-up phase takes approximately 96 hours. So for every shutdown where there are maintenance activities that needs a mechanical window, five days are needed in order to clear the mechanical window. If we consider a TAR with a duration of two weeks, in approximately 40-50 percent of the time no mechanical activities on the processing equipment can take place.

In addition, not all the time during the mechanical time window is necessarily utilized. The activities that are to be scheduled during the mechanical window requires a certain amount of time, so the time that each activity requires does not necessarily sum up to the total time allocated in the mechanical time window.

Chapter 5

TAR Optimization - TAR Analyser

As mention in the previous chapter Statoil and IBM launched in 2006 a project for optimizing the TAR scheduling for platforms on the NCS. The result were a software tool that could take a chosen TAR schedule for a given time horizon as an input and then calculate the expected production efficiency for this period. The main components and the associated work processes in the project "Optimize turnaround and shutdown frequency" is shown in Figure 5.1 [10].

As can be seen there are five main blocks. The two first are the process of defining the equipments, its failure modes and data, defining the corresponding maintenance activities and other modification activities. It is essential here to only implement those equipments and activities that causes a production loss, and also to focus on those that have an significant impact on the loss. Those equipments/systems and activities on the platform that have the most impact on the production loss are included in the model. Another important aspect in the two first blocks is to describe the deterioration behavior of the equipments and the associated production loss that these equipments state represent. Block number three defines the scenario for the analysis. That is the time horizon for the analysis, the planned production during this time horizon, the frequency and duration of turnarounds during the time horizon etc. Block number four is the construction of the analysis tool that is used to calculate the production efficiency during the chosen time horizon. An iteration process is foreseen in the work related to this block. The results for the production efficiency that the analysis gives should be reasonable and realistic. If the results differentiate much from real data given the same scenario, then one must go back and see if the model

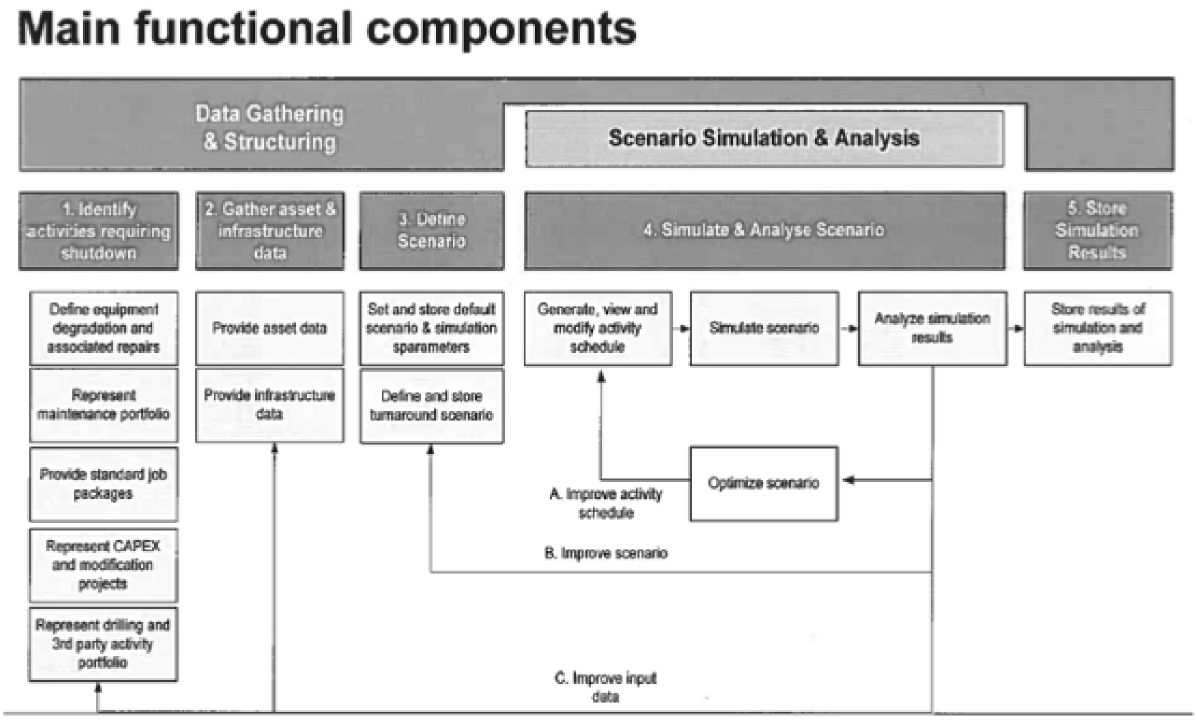

Figure 5.1: Main components in the project TAR Optimization.

are to be reconstructed. Meaning that some new components on the platform have to be included and other may be excluded, depending on how they contribute to the production losses. The last block is the storage of the results for later to be used as a decision tool when scheduling turnarounds.

5.1 TAR Analyzer - The objective

The objective of the software program TAR Analyzer is to provide a probabilistic distribution of the production volume of a given TAR schedule over a given time horizon. The program builds up a future TAR schedule for a chosen time horizon based on:

- Time interval between TARs and the time duration for these
- Planned activities with constraint on minimum frequency, required resources, type of shutdown required etc.

- Planned CAPEX (CAPital EXpenditure) and modification activities in addition to drilling and 3rd party activities
- Amount of total TAR time scheduled for corrective maintenance activities found necessary after planned technical inspection activities

All the planned activities for the time horizon are listed and distributed on the planned TARs period according to their criticality and due date (constraints). In addition, available time for each TAR is allocated for carrying out corrective maintenance activities that are found necessary during the last TAR period or initiated by technical condition inspections during the present TAR. The outcome is a probabilistic distributed measure in actual production, and with the potential production for the chosen time horizon as a input the program calculates the probabilistic production efficiency (PE).

Briefly explained the model simulates over a chosen time horizon the condition for a given number of equipments that makes up the processing system onboard the platform. Each of the different deteriorated states that a equipment can have, have a corresponding implication on the production, i.e. an equipment that are in a deteriorated state will cause a reduction on the production of oil during the time it is deteriorated. An equipments state can be reset through a maintenance activity. These maintenance activities requires a partly or a complete shutdown of the production in order to be carried out. Before the simulation start, a TAR schedule is generated for planned activities for the chosen time horizon.

5.2 The input

The input data format for the software TAR Analyzer are structured as follow:

- Scenarios
  - Parameters
  - Performance metrics
  - Maintenance strategy
    - Maintenance plan
    - Modification plan

  - Sub Scenarios
- Activities
  - Preventive Maintenance and Corrective Maintenance
    - Static equipment
    - Rotary equipment
    - Electro
    - Valves
  - CAPEX
- Standard Job Packages
  - Static equipment
  - Rotary equipment
  - Electro
  - Valves
- Facilities and Infrastructures
  - Production profile
  - Installation dependencies
  - Installation properties
  - Flotells
- Other pages
  - Version
  - Environment
  - Access verification
  - Export

The scenario section describes the global parameters for the TAR scenario, such as the duration for each TAR, the time interval between each TAR and the time horizon for the simulation. Other parameters such as number of iteration for the simulation (this will be described more thorough in Section 5.3) and the efficiency of available manpower, both for shutdowns that can be planned a certain time ahead and immediate shutdowns, are also global parameters that described in the scenario section.

Also in this section there are parameters for the maintenance strategy. This are parameters that are to be optimized in order to reach maximum production. Examples of such parameters are the slack factor that represent the proportion of the total man-hours available during a TAR that is kept aside for corrective maintenance/activities (repairs that is postponed to the current TAR and repairs that are triggered due to findings from inspections). Also a parameter that control whether temporary repairs are allowed. This is repairs that are performed during a planned but unforeseen shutdown and are executed in parallel to the maintenance activity that triggered the shutdown. In addition to these parameters for the maintenance strategy there is a parameter that controls whether to wait for a repair until next TAR or to schedule a shutdown before next TAR, upon observed degradation of an equipment. This parameter is a criticality parameter and is the combination of the probability for the degraded equipment to fail before next TAR and its impact on the total production.

The activity section has two sub-sections. The sub-section describing corrective and preventive activities for equipment which is this divided into four groups: static, rotary, electro and valves. Under each of these four groups individual equipments are described with failure mode characteristics and the corresponding corrective and preventive maintenance activities which reset the equipments state to OK. All failure modes are connected to different mean times to failure (MTTF), one for each transition between the equipment failure mode state.

Figure 5.2 [10] shows a transition diagram between these states. At a given point of time an equipment can be in four different states, marked as blue circles; OK, D (Deteriorated), F (Failed) or Temp (Temporary repaired). The red arrows show the deterioration of the equipment. Each of these arrows has a corresponding MTTF for occurring. The orange blocks shows show each state can be reset back to OK by an maintenance activity, with an exception of the state D that can transfer both to the state OK and Temp by two distinguish maintenance activities.

The other subsection is CAPEX activities or capital expenditure i.e. installation reconstruction activities.

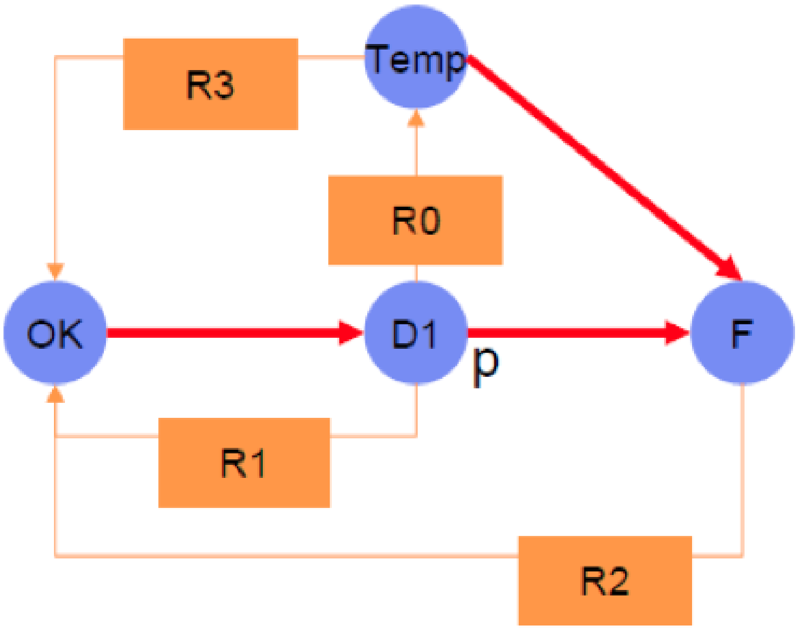

Figure 5.2: A transition model for the state of an equipments failure mode.

The Standard Job Packages section describes default duration and human resources involved in corrective and preventive activities. The duration are given in total number of days with restrictions to production if the specified numbers of manpower resources are applied.

The Facilities and Infrastructures section describes the production profile during the time horizon. That is how much oil are expected to be produced during the time horizon for the simulation. Also described in this section is the dependencies with other platforms and what degree of production reduction a shutdown on other platforms has and vica versa.

The last section is for executing a simulation. This involves a scheduling of all the activities during the time horizon and the simulation of the production during this time horizon.

5.3 Activity Scheduling and Simulation

When the input above is implemented, the program generates a maintenance plan for the time horizon. That is a scheduling of all the planned activities spread on the TARs during the time horizon. The planned activities can have constraints on what is the maximum duration between each time they are to be executed. The program tries to make the scheduling so that these constraints are counted for, but due to the amount of activities and corresponding constraints usually some constraints are broken. The program then make a report where it list up which activity that has not been schedule according to its constraint. Also the user can manually override the scheduling with moving activities after the plan is been generated, before the simulation starts.

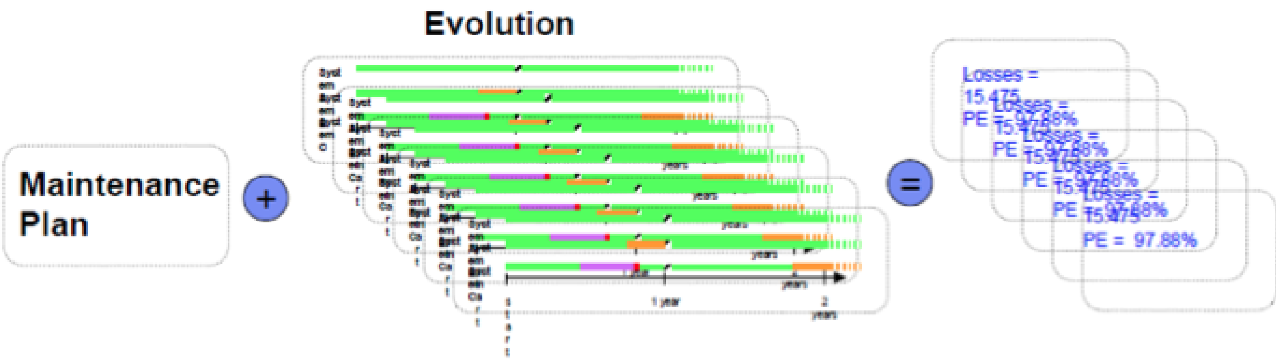

Figure 5.3: Illustration of the main stages in the model.

When the maintenance plan is finished the program can start to simulate the production loss. Since the production loss for one simulation is a result of a stochastic process, multiple iterations/evolutions needs to be conducted in order to get a probability density for the production loss. Each evolution gives a result for the production efficiency and other data such as the main equipment drivers for production loss. The main drivers are those equipment that contribute mostly to the loss when they fail or is in a deteriorated state. Figure 5.3 [10] illustrates the process from the obtaining a maintenance plan, obtaining several evolutions and the corresponding result for the production efficiency.

When considering the results, there are some important issues to bear in mind. When comparing real data with the achieved results from the TAR Analyzer that will be presented in the next chapter, not all the loss categorize that are found in Appendix A are included. This is because some of the sources for oil production loss is not included the TAR Analyzer model. For example equipments that is modeled in the TAR Analyzer does not cover losses due to equipments/activities from the well nor at subsea level. One exception is the risers which are included in the model. Also losses that falls under category 6; Weather problems, Authority restrictions, strike etc. are not included.

In addition, the production loss that is estimated from the model that can be related to some of the sub-categorize does not necessarily cover all of the actual losses. This is because not all of the equipments/activities that are sources of loss are included in the model. And even if the equipment is included, only given failure modes are included. The reason for this is that the total number of failure modes included in the model need to be limited in order for the program to produce the result in a reasonable amount of time. There are also limited data for the failure characteristics for each failure modes for the equipments (MTTF and the failure distribution). Since this program is under development, these issues are not the most important ones. The reason for this is because it is not a huge task to include more equipments/activities in the program data base, if the analysis of results shows that this is necessary. What is important with the beta version is that the results are reasonable according to the different maintenance plans given as input.

5.4 What can Statoil benefit from the results?

As mentioned in the example in Chapter 3, there are a 20-24 percent higher potential production of oil for the platform in the example given. And as mentioned, the single most important cause of lost production is TAR management and unplanned shutdowns. So if this program in the first stage can estimate the actual production for a specific TAR scenario and in the next stage optimize a maintenance strategy so that the production is maximized, it is clear that this very beneficially for an oil production company.

Chapter 6

TAR Scenarios

Three TAR scenarios will be presented in this chapter. The simulation is done for Plant A. The first scenario is with a one year interval between the TARs. The second is with a two year interval and the third is with a four year interval. The only major difference between the maintenance plan for these three scenarios is the time interval between the TARs. The common characteristics for these three scenarios is:

- The time horizon is 10 years
- The theoretical production of oil during the time horizon is 14500 kM3 of oil (125.4 million barrels of oil)
- Each TAR has allocated 30 percent of its time to corrective maintenance activities
- All scenarios have the same grade of personnel efficiency for both unplanned and immediate shutdowns
- All scenarios have the same criticality level for triggering a shutdown due to deteriorated equipment
- A total number of hundred iterations are conducted to calculate the results for each scenario

The result that will be presented here are: (1) Total oil production loss during the time horizon, (2) Production efficiency and (3) Proportion of oil losses from TAR, unplanned shutdowns and reduced production. Only results for the actual and the theoretical production of oil will be counted for here, not gas. The reason for this is as mentioned in chapter 3.1, that gas is seen as a by-product of the oil production. When comparing with the real data, it is the production of oil that is measured.

6.1 Case: 1 year interval between TARs

In this scenario the interval between the TARs is one year, and a total of ten TARs are conducted during the ten year horizon. Each TAR is scheduled for 240hours/10 days, which give a total of 2400 hours/100 days of scheduled TAR during the ten year period. A hundred iterations are conducted for this scenario.The average oil production loss from these hundred iteration is 2711 kM3. This average volume of oil production loss during this ten year time horizon represent a PE of 81.3 percent.

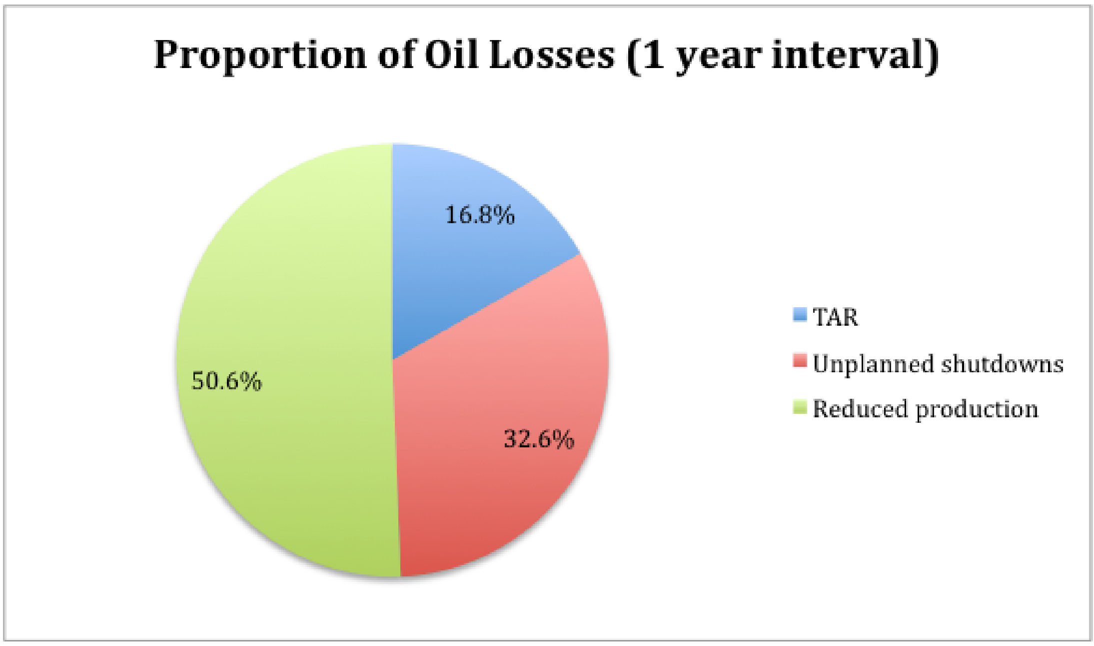

Figure 6.1: Proportion of oil losses for the one year interval scenario

In Figure 6.1 the proportion of total loss caused by TAR, unplanned shutdowns and reduced production during the ten year period is shown. As can be seen scheduled shutdowns as, i.e. TAR, represent 16.8 percent, unplanned shutdowns represent 32.6 percent and reduced production represent 50.6 percent.

6.2 Case: 2 year interval between TARs

In this scenario the interval between the TARs is two years, and a total of five TARs are conducted during the ten year horizon. Each TAR is scheduled for 240 hours/10 days, which give a total of 1200 hours/50 days of scheduled TAR during the ten year period. A hundred iterations are conducted for this scenario.The average oil production loss from these hundred iteration is 1885 kM3. This average volume of oil production loss during this ten year time horizon represent a PE of 87.0 percent.

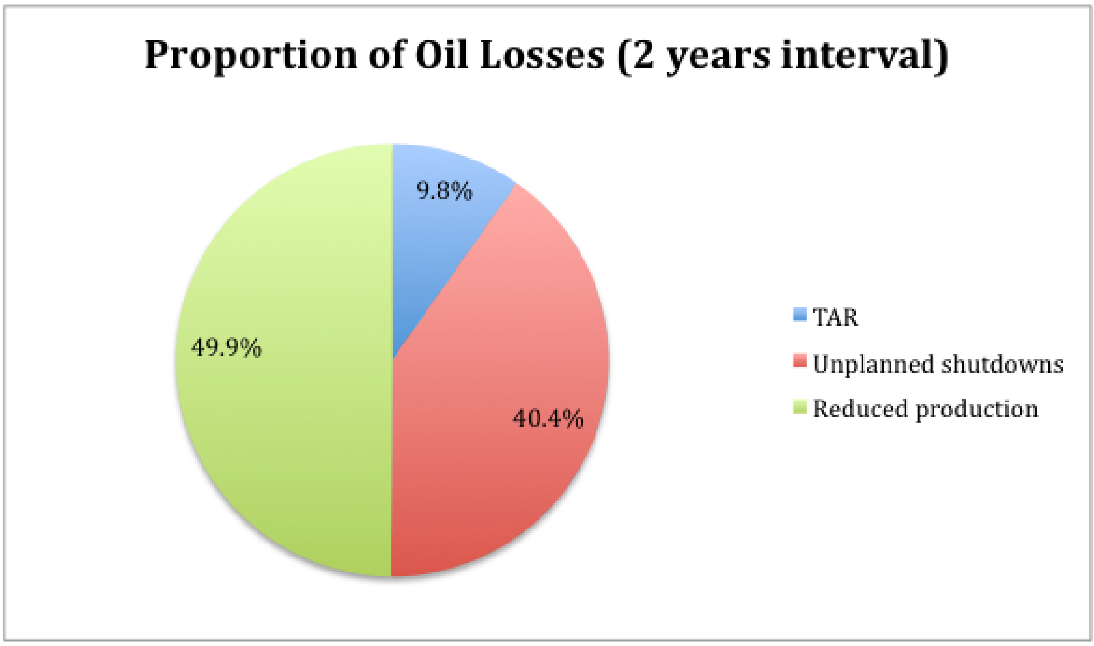

Figure 6.2: Proportion of oil losses for the two year interval scenario

In Figure 6.2 the proportion of total loss caused by TAR, unplanned shutdowns and reduced production during the ten year period is shown. AAs can be seen scheduled shutdowns as, i.e. TAR, represent 9.8 percent, unplanned shutdowns represent 40.3 percent and reduced production represent 49.9 percent.

6.3 Case: 4 year interval between TARs

In this scenario the interval between the TARs is four years, and a total of two TARs are conducted during the ten year horizon. Each TAR is scheduled for 408 hours/17 days, which give a total of 816 hours/34 days of scheduled TAR during the ten year period. A hundred iterations are conducted for this scenario. The average oil production loss from these hundred iteration is 1963 kM3. This average volume of oil production loss during this ten year time horizon represent a PE of 86.5 percent.

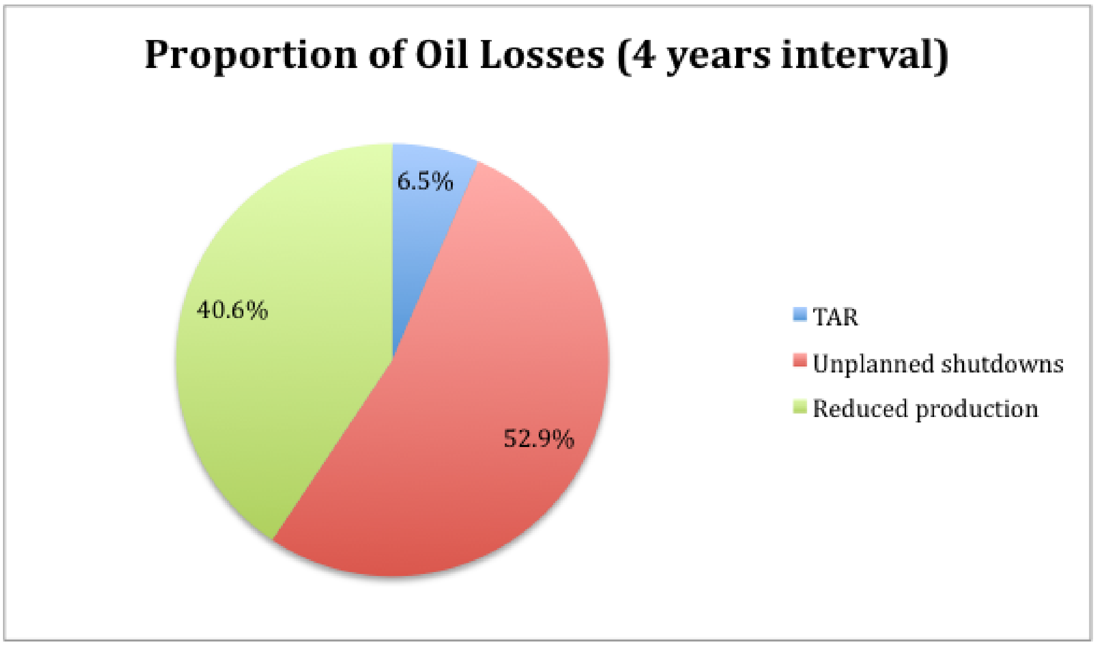

Figure 6.3: Proportion of oil losses for the two year interval scenario

In Figure 6.3 the proportion of total loss caused by TAR, unplanned shutdowns and reduced production during the ten year period is shown. As can be seen scheduled shutdowns as, i.e. TAR, represent 6.5 percent, unplanned shutdowns represent 52.9 percent and reduced production represent 40.6 percent.

6.4 Results

In the table below the results from the three scenarios are presented. The three rows presents the scenarios and the columns presents the loss in 1000 cubic meters of oil, the production efficiency, proportion of loss during turnaround, proportion of loss during a unplanned shutdown and proportion of loss due to reduced production, respectively.

Scenario	Loss (kSm3)	PE	% TAR	% Unplanned	% Reduced production
1 Year	2711	81.3	16.8	32.6	50.6
2 Year	1885	87.0	9.8	40.3	49.9
4 Year	1963	86.5	6.5	52.9	40.6

Chapter 7

Discussion of the results

This chapter will discuss the results from the two scenarios from chapter 6. The first section will compare the results from the program with the real data presented in Chapter 3. Section 7.2 will discuss and compare the results from the three TAR scenarios individually.

7.1 Comparing real data with the results from the program

The three scenarios in Chapter 6 had a production loss that was spanning from 1.885.000 to 2.711.000 Sm3 of oil during a period of ten years. This gives an average annual production loss that is spanning from 188.500 to 271.100 Sm3. Plant A had a production loss of 790.000 Sm3 during a period of 29 months, which gives a average annual production loss of approximately 326.900 Sm3. It is expected that the actual loss is higher than the losses estimated from the program since not all factors for loss are included in model. But regardless of this, the production loss estimated from the program is 60-80 percent of the actual loss. This indicate that perhaps more factors for loss needs to be added to the model, and also that the failure frequency of the existing equipment in the model perhaps need to be revised.

When looking at the proportion of the total loss between TAR, unplanned shutdowns and reduced production from the scenarios presented in Chapter 6, the losses due to TAR represent 6.5 to 16.8 percent of the total loss and unplanned shutdowns and reduced production amounts to the conjugate proportion 83.2 to 93.5 percent. Losses due to TAR are regarded as planned losses. The real data from the chart in Figure 3.4 showed that the distribution between these two categorize of losses was 56.8 percent for planned losses and 43.2 for unplanned losses. The results from the scenarios give a much higher proportion of the losses to unplanned shutdowns and reduced production compared to the real data from Figure 3.4. But further investigation of the results from the TAR Analyzer is needed in order to explain this difference.

7.2 Comparing the results from the scenarios

In Chapter 6 three scenarios are presented. The main difference between these is the time interval between conducting the TARs. The best result for the oil production efficiency was for the second scenario, with two year between the TARs. The two year scenario gave an production efficiency of 87 percent. The worst results was with one year between the TARs and the second best was with four years between the TARs.

When looking at the loss distribution between the TAR, unplanned shutdowns and reduced production for the three scenarios, it is clear that a shorter interval between conducting TARs gives a higher loss proportion that occur during conducting the TARs. The losses due to TAR (planned losses) was 16.8 percent with a one year interval, 9.8 percent with a two year interval and 6.5 year with a four year interval. It is also expected that the loss due to unplanned shutdowns increases with an increased time interval between the TARs. The reason for this is that the there is increased time between the preventive maintenance activities on the processing equipment, which leads to an increased possibility for the equipment to fail that again can trigger a unplanned shutdown of the platform.

7.3 Further work

My suggestions for further work on this subject are listed below:

- A thorough sensitivity study of the decision parameters for the TAR Analyzer (this work is under progress by Statoil at the moment), and to compare the results with each other to see whether the seem reasonable with what is expected.

- A thorough study of which equipments and their failure modes on a platform that contributes to the production loss and in which extent they contribute to the loss. A study of this was done in the pre-work for this thesis, but this data was limited since the investigation period was limited to 29 months. If one could have done a study over a longer period of time a better statistical representation could have been made of the frequency of failure modes and their related production loss. Such a study could maybe have excluded some equipments in the model and introduced others, and in that way estimate a realistic production loss.

- In the model the production loss at a given time in the simulation is summed up. Each state of a failure mode at a given point of time represent a certain reduced production. For example for on equipments failure mode the three different state OK, D (Deteriorated) and F (Failed) represent a reduction on the total production of 0, 5 and 20 percent respectively. This means that if we have five failure modes that are in the state F, and each state represent a reduction on the production of 20 %, then we have zero production. How much the production is reduced at a certain time as a function of the states of different failure modes of different equipment, is a complex calculation. A more thorough study of what the actual reduction on the production is for the different state of the system is beneficial in order to produce more realistic results.

Bibliography

[1] Magnus Rasmussen, *Driftsteknikk GK*. NTNU, 2003.

[2] TMR4160 - Driftsteknikk GK, *Course material*, 2011.

[3] Gas-compressor, webpage: *http://www.elliott-turbo.com/compressors*.

[4] Petroleum Safety Authority Norway, Webpage: *www.ptil.no*.

[5] Inge Lundhaug Berdahl, *Pre-work for this Master Thesis*. NTNU, 2010.

[6] Standards Norway - NS-EN13306, Webpage: www.standard.no, 2011.

[7] Micheal V. Brown, *Managing Shutdowns, Turnarounds and Outages*. Audel, 2004.

[8] Joel Levitt, *Managing Maintenance Shutdowns and Outages*. Industrial Press, 2004.

[9] Tom Lenahan, *Turnaround, Shutdown and Outage Management*. Elsevier, 2006.

[10] Statoils intranet, *All material are the property of Statoil*, 2011.

Appendices

1 Well equipment/activities			
Loss Category	Description	Loss (Sm3)	% of total
1.1	Planned activities on well equipment	1600	0.20
1.2	Well tests	6004	0.76
1.3	Operational problems on well equipment	0	0.00
1.4	Equipment failure and unplanned activities on well	56834	7.22
1.5	Leak of competence/ misaction on well equipment	0	0.00
1.6	Well operations to maintain / increase production	29536	3.75
	Sum loss Category 1	93974	11.94

2 Subsea equipment/activities			
Loss Category	Description	Loss (Sm3)	% of total
2.1	Planned activities on subsea equipment	404	0.05
2.2	Run-in and modification problems on subsea equipment	0	0.00
2.3	Operational problems on subsea equipment	0	0.00
2.4	Equipment failure and unplanned activities on subsea	460	0.06
2.5	Leak of competence/ misaction on subsea equipment	0	0.00
2.6	Modification project on subsea equipment	0	0.00
	Sum loss Category 2	864	0.11

3 Processing equipment/activities			
Loss Category	Description	Loss (Sm3)	% of total
3.1	Planned activities on processing equipment	147211	18.71
3.2	Run-in and modification problems on processing equipment	0	0.00
3.3	Operational problems on processing equipment	36366	4.62
3.4	Equipment failure and unplanned activities	218546	27.78
3.5	Leak of competence/ misaction on processing equipment	60805	7.73
3.6	Modification project on processing equipment	94610	12.03
	Sum loss Category 3	557538	70.87

4 TAR			
Loss Category	Description	Loss (Sm3)	% of total
4.1	Planned shutdowns (TAR)	45300	5.76
4.2	Prolonged turnaround	12635	1.61
	Sum loss Category 4	57936	7.36

5 Export			
Loss Category	Description	Loss (Sm3)	% of total
5.1	Equipment failure and unplanned activities on another installation	19474	2.48
5.2	Planned activities on export-terminal	17290	2.20
5.3	Equipment failure and unplanned activities on export-terminal	16076	2.04
5.4	Unavailable shuttle tanker and loading operation	0	0.00
5.5	Unavailable pipes for export	200	0.00
5.6	Reduced gas demand	0	0.00
5.7	Planned activities on another installation	15876	2.02
	Sum loss Category 5	68918	8.76

6 Other			
Loss Category	Description	Loss (Sm3)	% of total
6.1	Reduction due to Authority restrictions	0	0.00
6.2	Streak / lock-out	0	0.00
6.3	Weather problems	2865	0.36
6.4	Safety / emergency preparedness actions	3553	0.45
6.5	Other	1100	0.14
6.6	External power supply	0	0.00
	Sum loss Category 6	7518	0.96

	Sum Total loss Category 1- 6	786751	100.0