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Abstract:

Statoil is a prominent Norwegian actor in the oil and gas industry at home and abroad. Maintaining the offshore installations has gradually become more important in line with the installations age, increased HMS demands and the fact that the offshore industry is extremely capital intensive.

Management of shutdowns is an essential part of Statoil's strategy for safe and efficient operation of assets or plants.

The objective of the thesis is to investigate existing methods and tools that measures turnaround preparedness and propose areas for improvements. The work shall include a review of theory and practices related to performance indicators and address maintenance management with specific focus on measuring planned and unforeseen shutdowns.

The main tasks in this thesis were given in three points:

- Describe the state-of-the-art in key performance indicators related to maintenance management with specific focus on measuring shutdown preparedness.
- Review existing work processes, methods and tools that enables monitoring of shutdown preparedness.
- Investigate the shutdown preparedness and propose areas for improvement based on data collected from two different installations operated by Statoil.

Key performance indicators related to maintenance management has been given thorough account for, where different groups of indicators have been presented, how the KPI logic differs between different levels in the organization and the relationship between the indicators. We are separating between economic, technical and organizational indicators. Lagging indicators are indicators of past events and results – prior to a shutdown. Leading indicators are measurements of what will lead to the desired events and results.

Shutdown preparedness is measured through monitoring of indicators identified by the experts from Statoil and IBM. The indicators measure the quality & volume of shutdown-related work orders as they pass through the natural work order maturing process: Initiating, planning, execution and termination. Monitoring of the indicators is done by creating a database, and then to perform queries in the relational database management system, Microsoft Access.

Keyword:

Maintenance Management
Shutdown Preparedness

Advisor:

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NTNU
Norwegian University of
Science and Technology

Faculty of Engineering Science and Technology
Department of Marine Technology

MASTER THESIS

for

M.Sc. student Mats Gustav Andreassen

Department of Marine Technology

Spring 2011

Shutdown preparedness monitoring – case studies

The MSc. thesis will be concerned with the process to improve methods and tools for monitoring of shutdown preparedness and the implementation of opportunistic maintenance.

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During the period for this master thesis work the candidate need to have close cooperation with the Statoil.

The thesis must be written like a research report, with an abstract, conclusions, contents list, reference list, etc.

During preparation of the thesis it is important that the candidate emphasizes easily understood and well written text. For ease of reading, the thesis should contain adequate references at appropriate places to related text, tables and figures. On evaluation, a lot of weight is put on thorough preparation of results, their clear presentation in the form of tables and/or graphs, and on comprehensive discussion.

Three copies of the thesis are required. One of these should the candidate deliver to Statoil.

Starting date: 17th January 2011

Completion date: 13th June 2011

Handed in

Trondheim 17th February 2011.

Tom Anders Thorstensen

Associated Professor II

Preface

This master thesis is the final work of the Master of Science and technology degree in Marine Technology at the Norwegian University of Science and technology (NTNU).

The master thesis continues the work done in the project with the same name, Shutdown Preparedness Monitoring, during the autumn 2010. The work has been done for Statoil's Research Center at Rotvoll, Trondheim. In the Turnaround & Shutdown Optimization project initiated by Statoil and IBM, the improvement of turnaround and shutdown preparedness and performance was one of the main parts. In order to measure shutdown preparedness the team created indicators that measures the quality & volume of shutdown-related work orders, which I have continued using in my monitoring of shutdown preparedness at the same installations.

The work scope for the thesis is one semester, from the 17th of January until 13th of June. The observant reader will see that the date of delivery is one week later than this date. I was granted this extra week due to a two week delay, as my school report from my exchange program failed to arrive at NTNU, and thus gave me some problems.

As in the project work, the queries carried out in MS Access gave most of the difficulties and was the most time consuming part.

I would like to thank my tutor Tom Anders Thorstensen at Statoil for guidance during the work, and for providing me with relevant literature. I would also thank Lars Thuestad at Statoil for his assistance with the queries performed in Microsoft Access.

Trondheim June 21st, 2011

Mats Gustav Andreassen

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Statoil is a prominent Norwegian actor in the oil and gas industry at home and abroad. Maintaining the offshore installations has gradually become more important in line with the installations age, increased HMS demands and the fact that the offshore industry is extremely capital intensive.

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1   Introduction

1.1 Background

Statoil is an international energy company with more than 30 years of experience in the oil and gas industry. The offshore installations are complex plants with high demands concerning performance and profit making, as industry becomes more capital intensive. The fields grow older, and the need for a good maintenance strategy to minimize downtime and maximize production rates is increasing.

Turnarounds (TARs) and unplanned shutdowns are Statoil's single-most important cause of lost production. Management of turnarounds and shutdowns is an essential part of Statoil's strategy for safe and efficient operation of assets or plants. Statoil has launched several initiatives to improve its turnaround planning and execution process. The Turnaround & Shutdown Optimization project is developed by Statoil in cooperation with IBM as there is a need for minimalizing the negative effects a shutdown will have. The three main parts of the project was:

- Improve turnaround and shutdown preparedness and performance

- Optimize turnaround and shutdown frequency and duration for single installations

- Optimize turnaround frequency and duration across interdependent installations

(Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)

In the Activity A.3 – Shutdown Preparedness, the group developed a method for measurement of shutdown preparedness and utilization for shutdowns for maintenance work. They tested the method on two installations and prepared recommendations for continued development and implementation of the method. This master thesis is dealing with shutdown preparedness, and the process to improve methods and tools for monitoring of shutdown preparedness and the implementation of opportunistic maintenance. The shutdown preparedness monitoring will be based on the same methods used by the group described, and on the same installations. There will be a debate over the methods in use and the results. Hopefully it will be possible to point out trends from the measurements, and perhaps important differences between the two installations. Statoil will provide me with the data necessary in order to perform the measurements.

1.2 Statoil

Statoil is an international energy company listed on the stock exchange, with more than 30 years of experience in the oil and gas industry. Statoil has been one of the most important actor in Norwegian oil industry since early 70's, and has contributed to develop Norway to a modern developed country. The Government of Norway is the largest owner, with 67% of the shares. The ownership interest is managed by the Norwegian Ministry of Petroleum and Energy. Statoil is operating nearly 80 percent of all oil and gas production on the Norwegian continental shelf (NCS). Today Norway is one of the world's most productive petroleum register, and a laboratory for technology development. Statoil has also international target areas. As much as half of Statoil's exploration activity is now outside Norway's borders. The company has almost 30 000 employees, and is represented in 40 countries.

With a market value of approximately 400 billion Norwegian kroner, it is by far the most valuable country in Norway and the world's 13th largest oil and gas company by revenue, profit and market capitalization. In 2010, Statoil delivered total liquids and gas entitlement production of 1.705 million barrels of oil equivalent (mmboe) per day, down 6% from 1.806 mmboe per day in 2009. Only on the NCS the numbers were 1.374 and 1.45 mmboe in 2010 and 2009 respectively. (The Global 2000, 2010) (http://en.wikipedia.org/wiki/Statoil)

1.2.1 Business benefits

The initiating of the Turnaround & Optimization project is to reduce lost production. Lost production is defined as the difference between the actual production and the potential production (theoretical production target). According to the Shutdown Preparedness final report the estimated value of production on the NCS by Statoil was approximately 77 billion USD in 2009, derived from the average of 1.450 mmboe. But this value of production has a potential of increasing with higher Production Efficiency (PE). The total PE losses was in 2009 13.2%. A small increase of the production efficiency will transmit into great increase in production and thus profit.

The total amount of planned and unplanned work including turnarounds on process related equipment accounted for approximately 6% loss of production efficiency in 2009. This corresponded roughly to 4.6 billion USD. The numbers were almost equally divided on planned and unplanned shutdowns. Further the report states that *it is believed that improved planning of all activities requiring shutdown may reduce the overall need for shutdowns. The business potential is significant. A 5% reduction of the need for shutdowns through improved planning and preparedness will for instance reduce the annual production losses with 230 million USD per year*. (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)

2   Maintenance Management

According to the European committee for standardization maintenance management is:

> *"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 economic aspects."* (Maintenance Terminology, 2001)

Maintenance management cannot be understood without a good sense of the term maintenance.

2.1 Maintenance

Maintenance in everyday life is for most people the work of keeping something in proper condition. It is a broad term, and is defined by the European committee for standardization as:

> *"Combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function."* (Maintenance Terminology, 2001)

In the award winning Master Thesis by Hägerby and Johansson, an equipment performance figure is presented to explain the meaning of equipment's state. Before any action the performance is decreasing due to wear and tear from normal use. Action 1 shows that maintenance brings the equipment back to original state after a certain uptime. To further increase the performance of equipment, modification of the item or design changes are demanded (action 2 and 3).
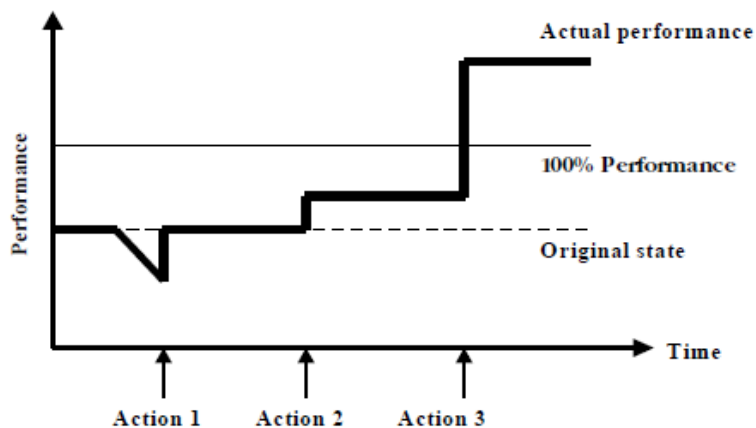
Figure 1 Equipment performance (Hägerby & Johansson, 2002)

Traditionally maintenance was only paid attention to in combination with failure. It was unsystematic and considered a necessary evil that reduced production. During and after the industrial revolution the view upon maintenance has changed. Condition monitoring of equipment was made possible due to technological changes, tougher environmental and safety demands and change in the people and organizational systems [Tsang, 2002] and today maintenance is generally accepted to be vital in terms of [Rasmussen, 2003]

- Safety and environment
- Availability (functionality, regularity, capacity)
- Economy

The enormous costs attended with production combined with the high incomes have made the oil and gas industry recognized to be one of the most capital intensive industries there is. As a result of this, the downtime costs are significant. The increasingly focus and requirements on safety and environment has forced the industry to take maintenance management more seriously than ever before.
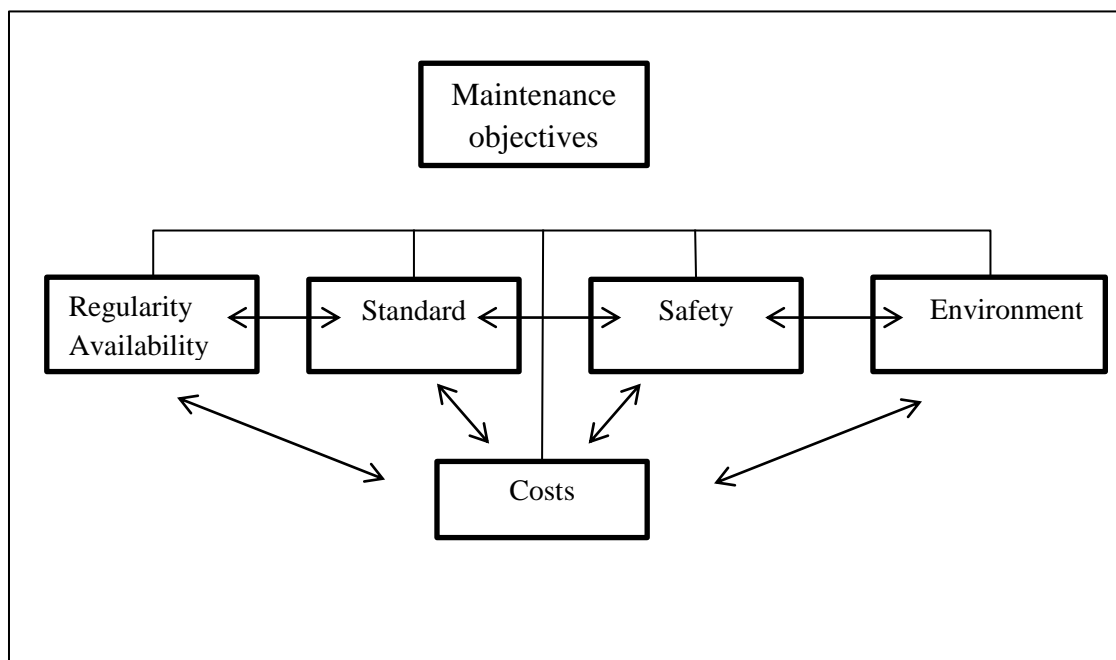
Figure 2 Main elements in the maintenance function objectives (Rasmussen, 2003)

Being vital in the maintenance organization, it should be stressed that the maintenance function adds value to an organization, mostly noted by increasing availability of assets.

2.2 Maintenance organizations

Maintenance organizations can roughly be divided between the repair-focused and the reliability-focused organization. The main difference between the two strategies is that the repair focused organization accepts that failure will occur, while the reliability focused does not. The repair focused organization focuses on fast repair of failed equipment, while the reasons for failure are to some extent ignored. The preventive maintenance performed is in other words poorly managed.

The reliability focused organization on the other hand focuses on internal control, strategy and maintenance management in order to prevent failure. The organization uses condition based maintenance to eliminate equipment failure. Reporting and analysis of maintenance history and other data is part of the management, and the continually improvement process is implemented throughout the organization. Although showing two types of organizational maintenance strategies, it must be mentioned that in most organizations one will find something from both types. The two types can be illustrated in a quality circle where the repair-focused organization is focusing on the right hand side while the reliability-focused is focusing on the whole circle in order to maintain the smallest failure rate possible from a safety, environmental and economic perspective.[Rasmussen, 2003]
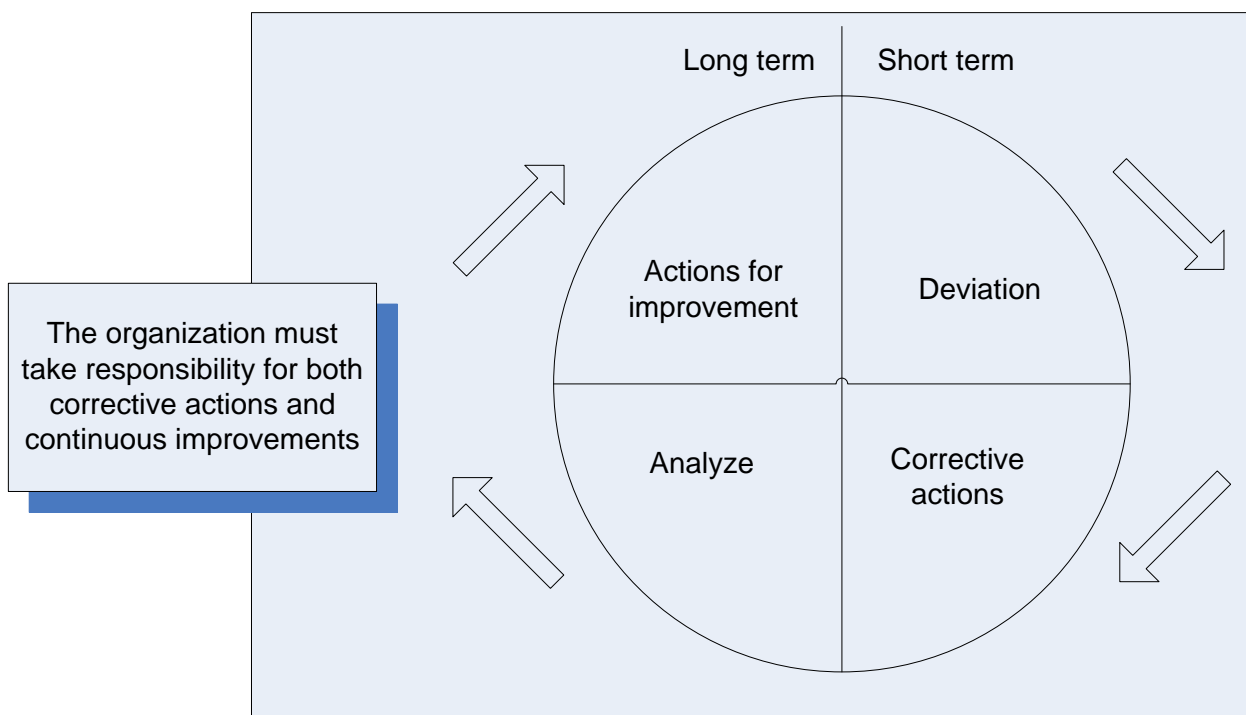
Figure 3 Long and short term maintenance management (Rasmussen, 2003)

Being a capital intensive industry, profit is often a drive power for changes. As mentioned earlier, maintenance adds value to an organization. Maintenance contributes to profitability through

- Extended life of assets
- Improved reliability and availability
- Enhanced and consistent product quality
- Continuity of production and supplies
- Quick response and repair times
  (Wilson, 2002)

2.3 Maintenance strategies

Maintenance can be divided between planned and unplanned maintenance, with each its subgroups as illustrated in figure 4. Planned maintenance is maintenance performed with a certain strategy.
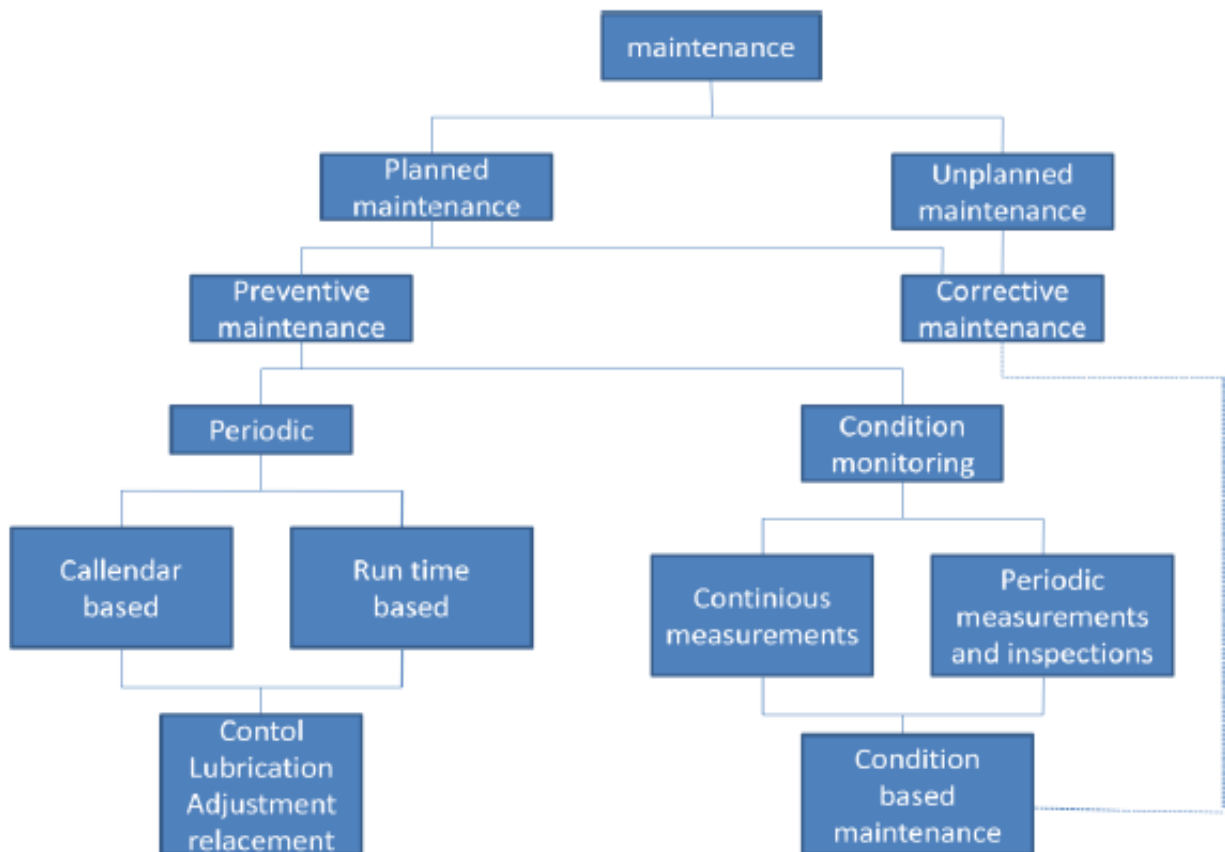
Figure 4 Maintenance types and control categories (Rasmussen, 2003)

2.3.1 Preventive maintenance

Preventive maintenance (PM) is planned and performed in order to prevent failures (direct PM), or find failures that may lead to breakdown (indirect PM). As seen from the figure, we further separate between periodic and condition monitoring.

Periodic maintenance is performed after predetermined intervals without taking the equipment's state into consideration. The interval may be calendar based or run time based. The equipment can be overhauled onsite or at a workshop, while equipment with strict restraints due to lifetime is replaced. Cleaning and lubrication are examples of periodic maintenance activities.

Condition monitoring inspects whether the equipment satisfies a certain standard or not. It has its advantage with equipment that deteriorates towards failure under a period of time, which will enable the condition monitoring to detect the fault. Functional testing, inspection, manual and automatic measuring are examples of condition monitoring, and they can be performed during operation or stop.

2.3.2 Corrective maintenance

Corrective maintenance can be both planned and unplanned, and is performed after failure. This strategy is used for low risk equipment due to both safety and economy. It can be planned hours or days before an expected failure, or as equipment run until failure. Unplanned corrective maintenance will cause unplanned downtime and thus be more expensive. [Wilson, 1999]

The link between condition based maintenance and corrective maintenance needs further explanation. If the condition based maintenance find needs for a corrective action, the same routines as in corrective maintenance is followed. This is called condition based maintenance, and is part of the preventive maintenance. [Rasmussen]

Turnaround maintenance (overhaul) can be preventive, but is applied to whole installations due to the standstill. Some equipment on a long time operating installation may need maintenance or replacement. The turnaround maintenance will reduce costs of the maintenance and production and improve performance.

2.4 Maintenance management circle

In order to establish the maintenance strategy Reliability Centered Maintenance is central tool. RCM is one of the qualitative methods available in order to establish a maintenance strategy, which is the basic data any maintenance management system (MMS) is built upon. (Rasmussen, 2003).

The Norwegian Petroleum Directorate has developed a maintenance management model, called the Maintenance Management Circle, which is based on the structure of a quality system. According to NPD the use of self-assessment as a method for improving a company's MMS has not been frequently applied by the operating companies on the Norwegian Continental Shelf. The NPD developed a method for systematic and comprehensive assessment of the company's own maintenance management system. They wished to contribute to a general improvement of the quality of the operator's system for managing safety-related maintenance and also provide better predictability for the operators in terms. (Øxnevad & Nielsen, 2000) It should also aid the personnel by standardizing the procedures for the maintenance work

Previously to the project performed by NPD, they claimed there was no common understanding in the industry of what a MMS really is. A goal was therefore to design the model that would be recognized and accepted by the petroleum industry in Norway.
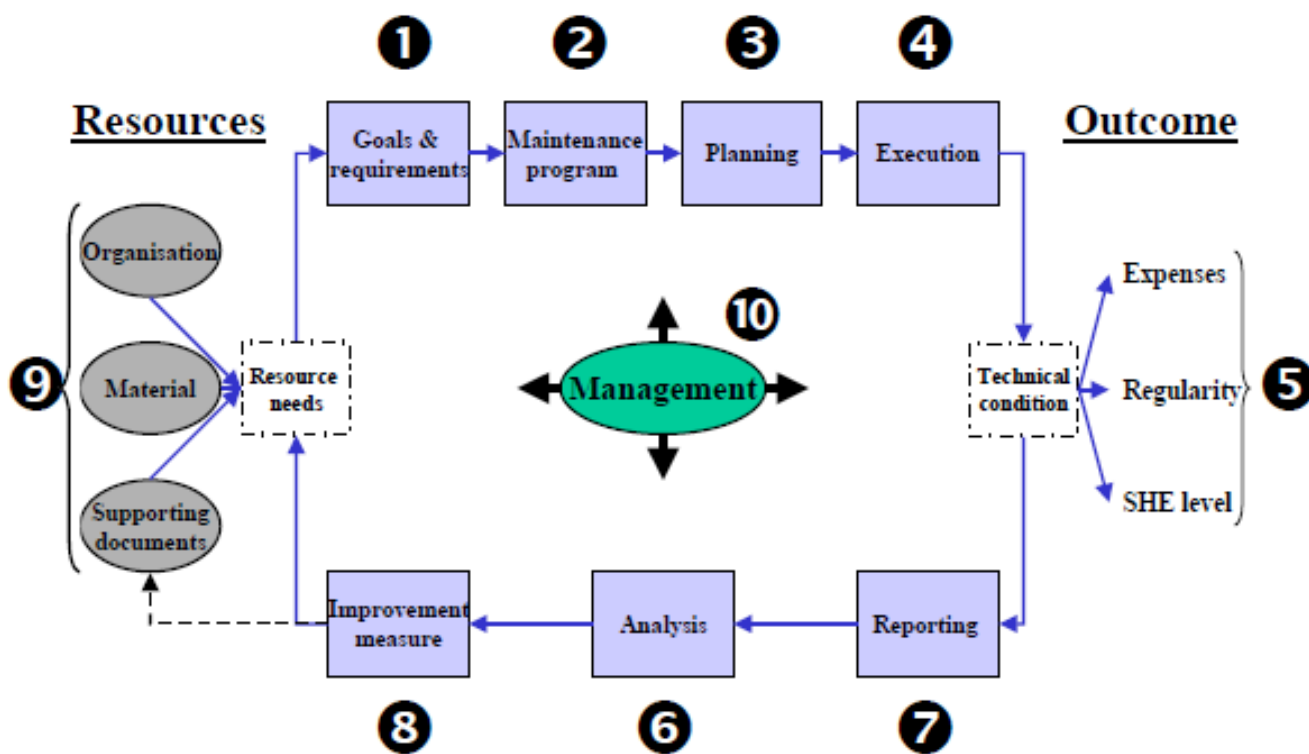
Figure 5 Maintenance Management Circle (Hägerby & Johansson, 2002) Internal DNV development of the NPD

The MMC illustrates the process the management of the maintenance function needs to go through in order to reach its goals, illustrated as **outcome** (5) in the circle. The goals of the maintenance function are as previous mentioned to optimize expenses, regularity and safety, health and environment. The resources any organization have (9) are used in different activities (1-4, 6-8) by the **management** (10) in order to reach those goals.

In order for a company to improve it need goals and requirements and a way to measure progress towards these goals. Key performance indicators are a central part of this measurement, and will be thoroughly review later. A maintenance program, such as RCM and RBI give guidelines about maintenance strategies for equipment, i.e. what actions should be performed and when. Planning is synonymous with strategy, and vital for efficient maintenance work. The execution is the operational maintenance work done, and includes training of personnel, handling of different permissions, reporting guidelines and finally control of the jobs. In the reporting stages the maintenance work is monitored, which form the foundation for the analysis of the work done. Improvement **measurement** is necessary since without measurement there can be no certainty of improvement. (Øxnevad & Nielsen, 2000)¨

The foundation for this process is the **resources** of the organization, which is the organization itself and the competence in it. Its materials consist of tools and spare parts used for the maintenance work and the technical documents for the process. (Øxnevad & Nielsen, 2000)

2.4.1 Reliability Centered Maintenance

A maintenance program is as mentioned an integral part of the management circle. RCM is a process to ensure that assets continue to do what their users require in their present operating context. (Moubray, 1997) The advanced optimization technique has its origin from the aviation industry in the 1930s as security of the travellers gained more attention. It is defined as:

> *RCM is a method for establishing maintenance strategies for all equipment units in an installation based on internal and external criteria's related to safety, environment, operation and economy. RCM views the equipment units in a system-perspective based on functional needs, functional failure and the preventing of these failures.* (Rasmussen, 2003)

The method can be implemented in several phases of an installations life cycle, but in order to be evaluated as a RCM process it must fulfill the minimum criteria set by the standard SAE JA1011, Evaluation Criteria for Reliability-Centered Maintenance: The following questions must be answered satisfactorily (Netherton, 1999):

1. What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?
2. In what ways can it fail to fulfill its functions (functional failures)?
3. What causes each functional failure (failure modes)?
4. What happens when each failure occurs (failure effects)?
5. In what way does each failure matter (failure consequences)?
6. What should be done to predict or prevent each failure (proactive tasks and task intervals)?
7. What should be done if a suitable proactive task cannot be found (default actions)?

Furthermore every question also has its fixed criteria in order to answer the questions satisfactorily. (Rasmussen, 2003) Advocates **gathering of information** as the first step, where the establishment of an RCM team often is the best solution. Documentation, general arrangement sketches and system description is essential and background experience in the sense of failure and failure frequencies is useful if available. Step two is **identification and grouping of system/equipment**, with the information from step one as a basis. The data's are here edited for each system according to system limits and equipment in the system. There exists a general grouping system for both ships and

offshore industry. Step three is the Failure mode, effects, and criticality analysis (**FMECA**), which is an analytical method including criticality analysis used to decide the probability of failure modes measured up against the criticality of these failures. The significant units are identified for preventive maintenance. Significant units are those who will affect safety or production availability if failure occurs, or those units who can have their maintenance cost considerable reduced if repair is done at an early stage after failure. The non-critical equipment failures may be repaired after failure, and thus has the strategy corrective maintenance. The critical failures should be avoided, and are categorized as **preventive maintenance (PM) task**.PM tasks are the fourth and last step of the RCM analysis. The PM tasks must be evaluated in terms of applicability and cost. It may not be a good option to perform PM, which will result in either planned corrective maintenance or redesign if the risk is not acceptable.

A method similar to RCM worth to mention is Risk Based Inspection (RBI). It is a systematic method where the most efficient inspection schedule for an installation is found. The safety and reliability is increased as the costs are reduced. As in the RCM analysis the probability and consequence of failure for critical components is the key. But as the RCM analysis focuses on the best maintenance strategy, the RBI focuses on the optimal inspection strategy.

3   Shutdown Monitoring

3.1 R&D project Turnaround & Shutdown Optimization

As mentioned in the introduction Turnarounds (TARs) and unplanned shutdowns are Statoil's single-most important causes of lost production. This project is developed by Statoil in cooperation with IBM as there is a need for minimalizing the negative effects a shutdown will have. The three main parts of the project was:

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- Optimize turnaround frequency and duration across interdependent installations
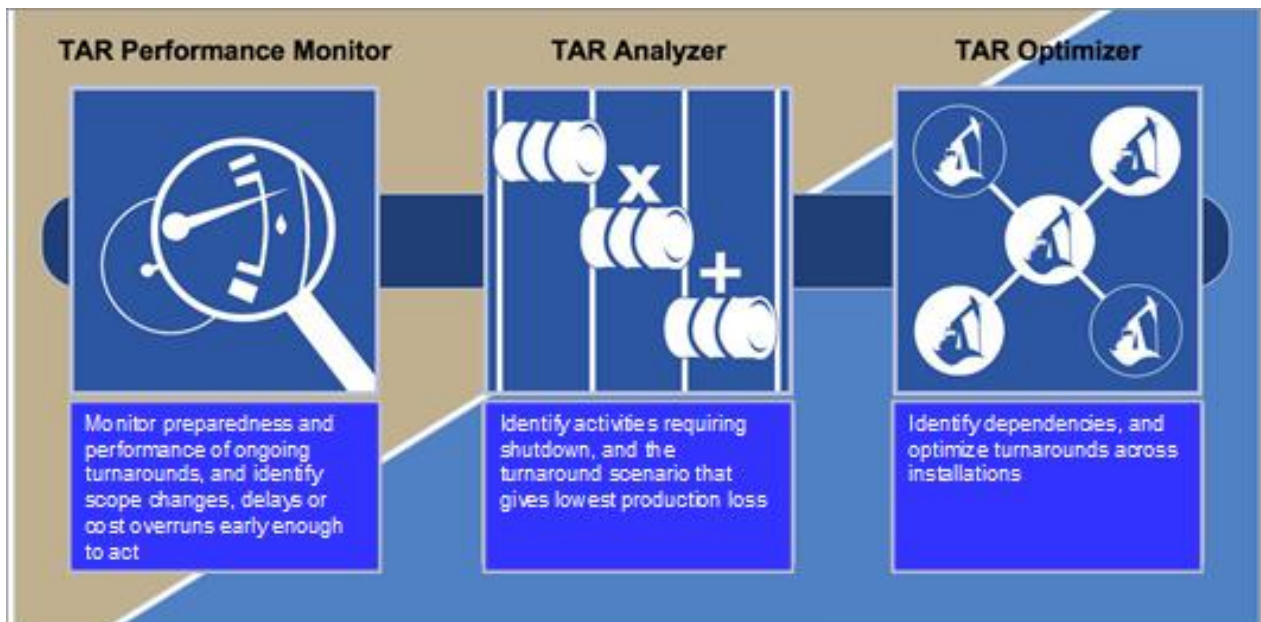
Figure 6 Three main parts of the T&S Optimization project

The TAR Performance Monitor part consists of "Turnaround Management assistant", "Turnaround Performance Monitor" and "Shutdown Preparedness Monitor" which is the topic of my project. Previous to my study a method for measurement of "shutdown preparedness" and "utilization of shutdowns" for maintenance work has been developed, which I will continue using.

The method is based on the assumption that all possible shutdown-related work orders are matured in accordance with the process illustrated. (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
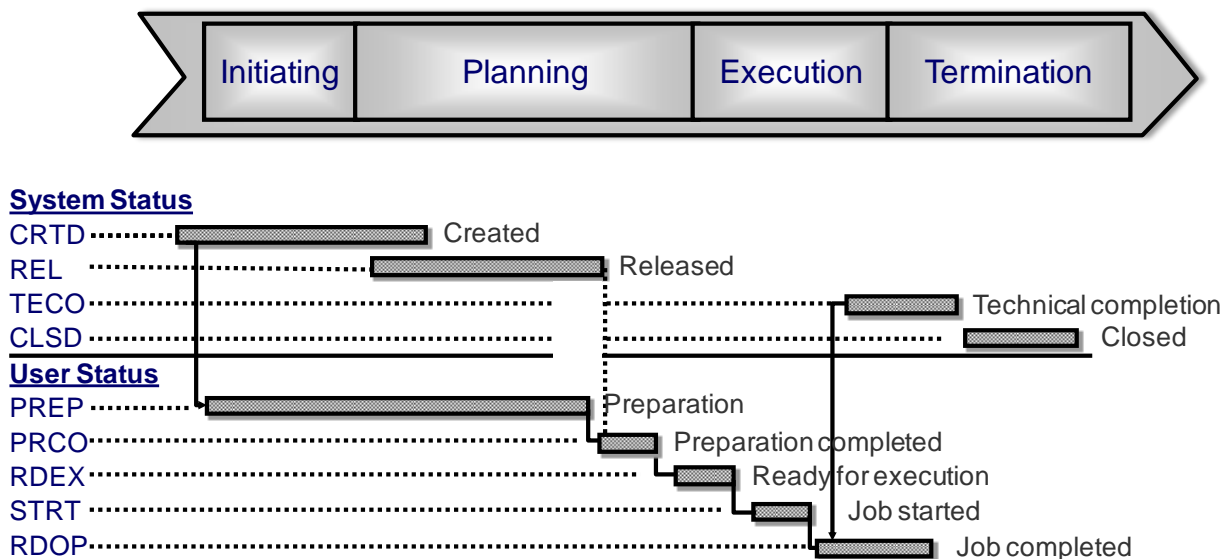
Figure 7 SAP work order life

Terms used in Work Orders in SAP ref figure 7.

System Status (set by the SAP system)

CRTD: Work Order created

REL: Work Order released (approved for execution)

TECO: Work Order technical completed

CLSD: Work Order closed

User Status (set by user of SAP)

3.2 Logistic tools

In Statoil a program called SAP (Systems Applications and Products in Data Processing) is the logistic tool used for "corporate governance". This is a module based program that contains accounting, economics, sales and distribution, purchasing and inventory management, logistics, maintenance, production and personnel management. The system for maintenance management is most relevant with regards to shutdown preparedness monitoring. As mentioned the "life" of the work orders follow a logically work flow, and the SAP user status shows the progress of this work order development.

The categories for maintenance work are as follows:

- PM01 – Unscheduled maintenance order (Corrective maintenance)
- PM02 – Maintenance program order (Preventive maintenance)
- PM03 – Modification order (Mod.)
- PM04 – Cost order
- PM06 – SAS change order
- PM10 – Project order
- PM20 – Project order, time only. No cost

(Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)

From the SAP all work orders related to shutdown can be extracted, where one can find details on work hours estimates, location, system, shutdown needed, status and creation and closure. The raw date used to measure shutdown preparedness was made available from the SAP as excel dump from a built in functionality in the program.

3.3 Indicators

Shutdown preparedness will be measured through monitoring of indicators identified by the group, that measure the quality & volume of shutdown-related work orders as they pass through the work order maturing process illustrated above. But in order to use the indicators one should understand what an indicator really is.

Previously we have separated between repair focused and reliability focused organizations, thus with the conclusion that most organizations uses something from both groupings. Shutdown monitoring as performed by Statoil in this project belongs to the reliability focused group, as it consists of reporting and analysis of maintenance history from the two installations, and the continually improvement process is implemented by the group.

As explained earlier, maintenance has seen severe changes since the industrial revolution. Earlier, financial measures were the only vital measurement describing performance in an operation in the company, business are or department. Now other performance measurements may prove to be equally important. According to NS-EN 15341 an indicator is defined as

> *Measured characteristic (or set of characteristics) of a phenomenon, according to a given formula, which assess the evolution. (Indicators are related to objects)* (Maintenance Key Performance Indicators, 2007)

Indicators are thus strongly related to performance measurements. The purpose of performance measurements is to provide a base for improvement, since without measurement there can be no certainty of improvement.

3.4 Key performance indicators

Key performance indicators can be defined as

> *KPI's are financial and non-financial metrics used to quantify objectives to reflect strategic performance of an organization* (Maintenance Key Performance Indicators, 2007)

KPI's, also known as Key Success Indicators (KSI), help an organization define and measure progress toward organizational goals. The difference between an indicator and a key performance indicator is to be shown later. The idea is to give the organization defined goals and a way to measure progress towards those goals. It is thus a base for improvement, since without measurement there can be no certainty of improvement [how an organization defines and measures progress towards its goals [F John Reh]. The indicators will vary from organization to organization. A hospital may have as one of its Key Performance Indicators the number of patient's treated during a year, while a university may focus on publications per professor. No matter the organization, the key features and objectives can be summarized as: (Solutions, 2003)

- A numerical, objective measure of performance
- Key to the strategic business objective
- Actionable and influenced by the relevant stakeholder/manager
- Accountable to a stakeholder/manager
- Output oriented, not focused on input or activity
- Be possible to calculate with limited efforts and within limited time

Objectives of KPIs are to:

- Measure for continuous performance
- Measure for internal and external benchmarking
- Measure to set incentives.

Ideally good KPI's that reflect organizational goals are used as a performance management tool – to manage performance. Another aspect that may be important in some organizations is the motivation factor. KPI's may give each employee in an organization a picture of what's important, of what they need to make happen. If the KPI's, their target and their progress are exposed, it will motivate people to reach those KPI targets. There exist a wide range of proposed categories for KPI's, and F. John Reg suggest the following sub-categories of KPI's (Reh)

- **Quantitative indicators** which can be presented as a number.
- **Practical indicators** that interface with existing company processes.
- **Directional indicators** specifying whether an organization is getting better or not.
- **Actionable indicators** are sufficiently in an organization's control to effect change.
- **Financial indicators** used in performance measurement and when looking at an operating index

With focus on maintenance management (Maintenance Key Performance Indicators, 2007) describes a system for measuring maintenance performance, with the aim for helping organizations in all sectors to improve their asset maintenance efficiency and effectiveness in pursuit of better global performance and competitive advantages. The standard suggest a structure of 3 types of KPIs

- Economic Indicators
- Technical Indicators
- Organization Indicators.

Later these 3 types of KPIs will be used to exemplify the different levels of where to use the indicators.

3.5 Maintenance indicators

There exist numerous examples of different indicators for measuring performance, and as in this case, maintenance performance. Following are some common indicators for the maintenance management created by (Hägerby & Johansson, 2002)

- OEE (Overall Equipment Efficiency)
- Cost of lost production
- Relation between costs for PM and CM
- Contractor maintenance costs as percentage of total maintenance costs
- Maintenance overhead costs (maintenance management) as percentage of total maintenance costs
- Spare part inventory turnover
- Costs of poor quality, distribution on the relevant causes
- Number of incidents resulting in employee absence
- Costs of emissions (maintenance related)
- Required availability level of safety equipment (as it effects the amount of maintenance required)
- Preventive maintenance costs and/or hours as percentage of total maintenance costs/and or hours.
- Maintenance costs
  - As percentage of turnover
  - As percentage of fixed assets
  - Per unit of production
- $\dfrac{\text{Total operating hours}}{\text{number of breakdowns}} (MTBF)$
- $\dfrac{\text{Breakdown maintenance hours}}{\text{number of breakdowns}} (MTTR)$
- $\dfrac{\text{Hours of maintenance training}}{\text{total maintenance hours}}$
- $\dfrac{\text{Effectiveness}}{\text{cost efficiency of PM}}$

Although being maintenance indicators, they can be divided between the 3 types suggested by the Maintenance standard (Maintenance Key Performance Indicators, 2007). It can easily be argued for that all indicators including 'cost' are **economic indicators**, for instance costs of maintenance, lost production etc. **Organizational indicators** are the ones concerning the personnel. Of highest interest is the maintenance man-hours. The **technical indicators are** all the indicators related to operational time, for instance MTBF and MTTR. The borders between these types of indicators are overlapping, as all the technical indicators to some extent is affecting the economy and vice versa. Dividing the indicators in groups like this does offer an understanding of the differences between the indicators. But it is anticipated that the usefulness of dividing the indicators regarding to whom they are to be used by in the organization, is of higher interest.

3.6 KPI logic and categories

However the defined types of KPI's, the complex nature of the indicators are divided further.
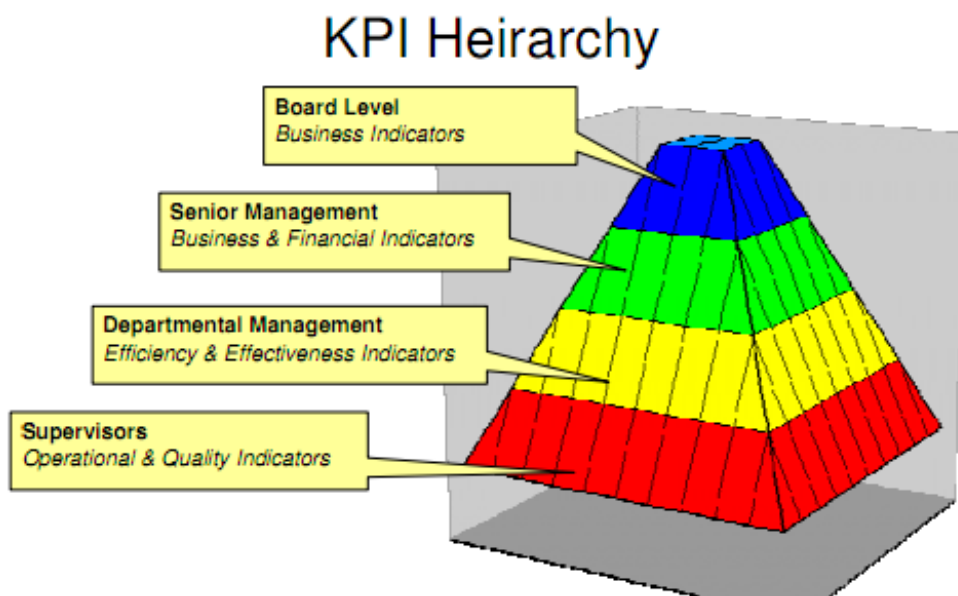
Figure 8 KPI hierarchy (Mills, 2010)

Illustrated is a KPI hierarchy by Simon Mills. In this model there is a clear relation between level of indicators and level of cooperation level. At board level the only relevant indicators are business indicators. At the senior management both business and financial indicators are to be dealt with. At departmental management efficiency and effectiveness indicators are relevant, and the supervisors are working with the operational and quality indicators. This direct hierarchy gives a presentation of how the indicators can be divided between the levels of cooperation, in its simplest way.

A three level maintenance KPI model have been created in the award winning thesis by [Hagerli and Johanson].The KPI's are here adjusted according to the level in the maintenance organisation in which it is to be used. The hierarchical breakdown of indicators consist of the top level, Main KPI's, that are aimed at corporate level, the middle level, Basic KPI's, that are aimed at the maintenance management level, and at the bottom - the Performance Indicators, aimed at the functional level/supervisors/operators.
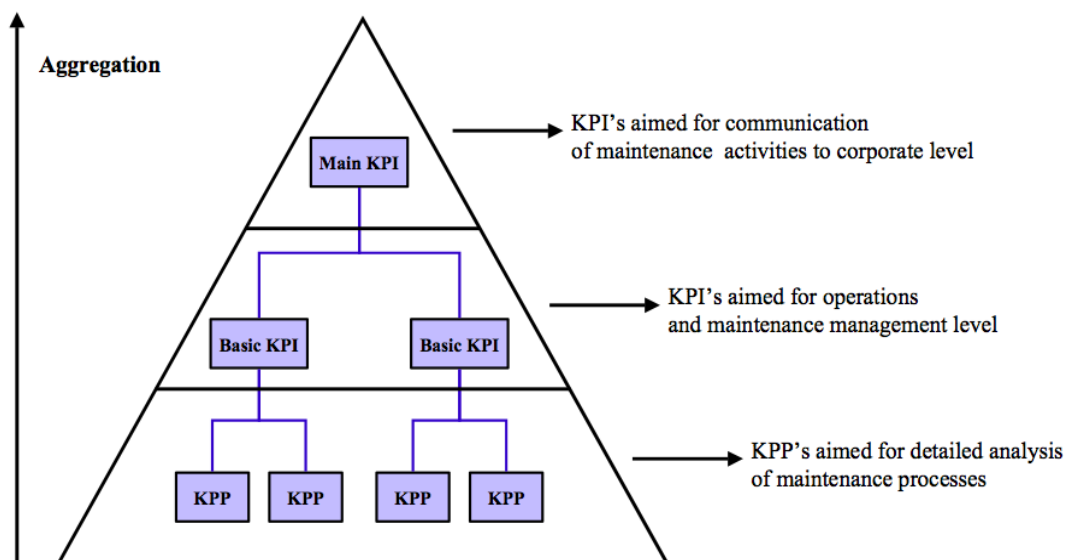
Figure 9 Hierarchical breakdown of maintenance indicators (Hägerby & Johansson, 2002)

In the figure we are introduced to the terms basic KPI and KPP. KPP's are Key Performance Parameters or just Performance indicators. The introduction of the new parameters is only a way of separating the indicators logically regarding to whom they are aimed for. The idea behind breaking the indicators down like illustrated above, is to make clear separation regarding who is to use the different indicators. With these borders the indicators are effectively separated between different levels of management. Now the supervisors for instance can focus on the indicators that are relevant to them and which they are able to manipulate.

(Gelder & Pintelon, 1992) Have proposed a three level classification in the maintenance organization where the top management does the strategically planning, the middle management the tactical planning and the supervisors the operational planning. They are working for the same super eminent objectives which are high availability and low maintenance costs. *The strategic planning is concerned with provision of production resources to ensure company's competitive capabilities. The decisions involve e.g. consideration of capacity, technology and investment criteria to retain or increase availability and keep maintenance costs low.* (Thorstensen, Lifetime profit modelling of ageing systems utilising information about technical condition, 2008)

The tactical planning's contribution concerns the maintenance strategies in use, like the Reliability Centered Maintenance method, also to ensure available and reliable equipment and a cost effective solution. They specify the direct activities to be performed by the operators, the interval for these

activities and the need for resources such as spare parts in case of repair or replacement of failed parts.

The final level is the operators which have the responsibility for the direct maintenance activities. They are also responsible for the sequences, in which the work orders are to be performed by, which is important in terms of both availability and profit. Some jobs are given higher priorities than others, e.g. those that may affect availability or the environment, and thus need to be performed before lower priority jobs. The availability of spare parts, workers and equipment is also something that needs to be taken into consideration by the operational planning.

3.7 Relations between indicators

Worth mentioning is the relation between the different levels in the management regarding the indicators. In the maintenance function there exist a flow of information and needs/requirement between the different levels of management. The KPPs are aggregated to calculate basic KPI's, which then again are used to calculate main KPI's.

3.7.1 Main KPI

The communication of maintenance activities to corporate level, main KPI's, are often of the economical type, or business indicators as from the model by Mills. The board has to answer to owners etc. and the economic indicators are of highest relevance here.

Total Maintenance Related Costs per Turnover, $TC_{Maintenance}$ is an example of a Main KPI in the maintenance performance. $TC_{Maintenance}$ consists of cost of lost production due to maintenance, redundant capacity cost and direct cost due to maintenance, $DC_{Maintenance}$. Cost of lost production is naturally critical in a capital intensive industry like the oil and gas industry. Redundant capacity cost is whether unnecessary resources are tied in the installation or if supplementary redundant equipment could increase the efficiency of the plant. $DC_{Maintenance}$ is the direct cost connected with maintenance work, such as PM costs, unplanned CM cost, planned CM cost etc. as illustrated in Figure 10. For the top management the $TC_{Maintenance}$ indicator is a foundation for their decisions, the indicator to whom they act in accordance with. They don't necessarily mind the material cost from the direct maintenance, even if its outcome is important for the Total Maintenance Related Cost per turnover. A general accusation towards the top management is that they are too focused on the cost, and not the driving forces and the possible earnings generated by these costs. This must be seen in relation with the historical perspective upon maintenance. The development has been toward increased attention towards maintenance and its positive effects on availability and production efficiency, and HSE. Norway and Statoil has for decades been a leader in the development in the offshore industry, and it is presumed that the accusation towards the top management is most valid for developing countries.
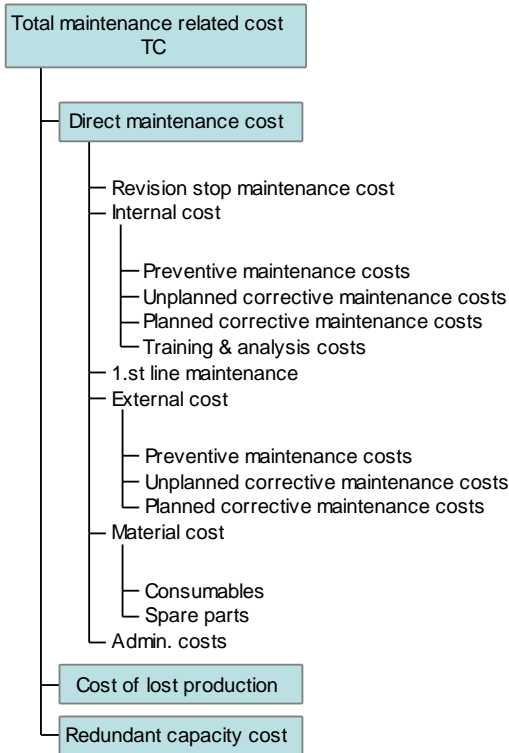
Figure 10 Total maintenance related cost (Hägerby & Johansson, 2002)

3.7.2 Basic KPI's

The KPI's aimed for operation and management level can be derived from the Main KPI's. The costs that all together form the $TC_{Maintenance}$ are basic KPI's, such as $DC_{Maintenance}$
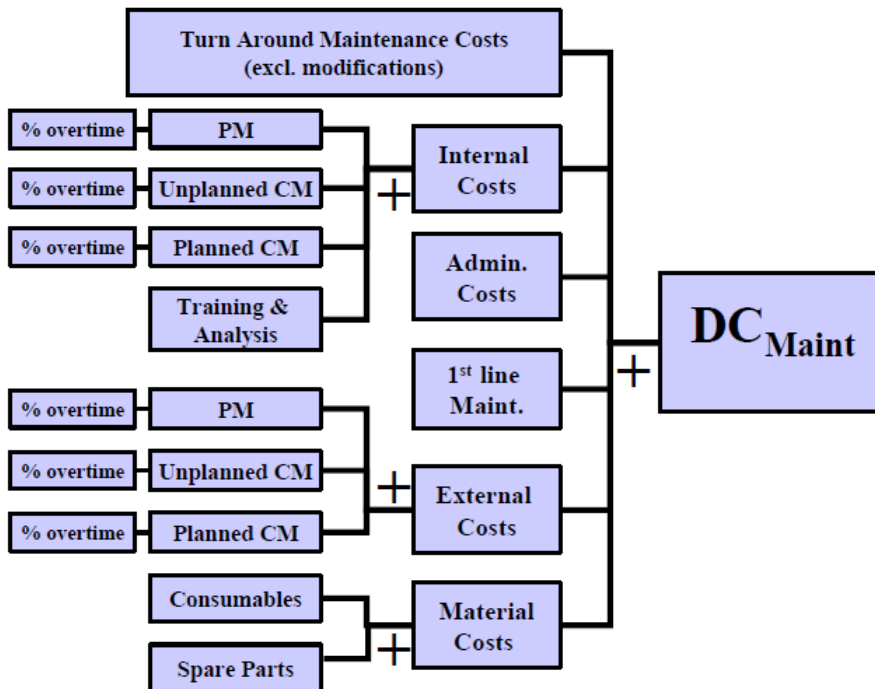

Figure 11 Constituent parts of KPI "DCmaint"

As you would expect there are many constituent parts, or Performance Indicators, that form the Direct Cost of maintenance. Minimizing costs is the super eminent goal, but not on the expense of for instance availability or HSE. Optimizing maintenance costs is therefore a more accurate term, as simply reducing $DC_{Maintenance}$ continually, is bound to eventually transmit into increased failure rates.

Regarding the division between the economic, technical and organizational indicators introduced in Chapter 3.4 -Key performance indicators it is safe to say that this "second level" indicator is still inside the boundaries for the economic indicator, although more technical than the Main KPI meant for the corporate level.

3.7.3   KPP

Performance indicators aimed for detailed analysis of maintenance processes. KPPs are affecting the Basic KPI directly. Some examples extracted from Figure 11:

- Administrational costs
- Internal costs (PM, unplanned CM, planned CM, training and analysis)
- External costs (PM, unplanned CM, planned CM)
- Material costs
- 1st line maintenance

There is still a predominance of the economic indicators (over technical and organizational). Being indicators that together constitute the Direct Maintenance costs, $DC_{Maintenance}$, this is natural.

It is clear that the different level of management has a different view upon the different indicators. As the top level management looks upon as $DC_{Maintenance}$ as a Basic KPI, the same indicator figures as a Main KPI for the middle management. And further a PI from a top levels point of view may appear as basic KPI's from a maintenance management point of view.

3.8 Leading and lagging indicators

However the types of KPI's, there are two undisputable categories of indicators, leading and lagging indicators. Lagging indicators are of past events and results, in the case of shutdown monitoring of an installation this is the process prior to a shutdown. Leading indicators are measurements of what that will lead to the desired events and results; here the focus is on utilization of opportunistic maintenance, i.e. utilization of maintenance opportunities when during shutdown.

In the report Turnaround & Shutdown Optimization, Activity A3 – Shutdown Preparedness, we have a suggestion for measurement of shutdown preparedness, which is through monitoring of indicators that measure the quality and volume of shutdown related work orders as they pass through the process mentioned (work process: preparation, preparation completed, ready for execution, job started, job completed)

The leading indicators are divided into quality indicators, which measure the quality of the planning work, and volume work order indicators with associated man-hours. Presented are the indicators selected for measurement of shutdown preparedness

Indicator	Description	Value			Comments
		Satisfactory	Should be improved	Not satisfactory	
Q1	Number and percentage of work orders with one or more operations with no or unsufficient man-hour estimates	Low	Medium	High	If a work order is without man hour estimates, it will be difficult to get hold of required resources for shutdowns with short lead time, in particular
Q2	Number and percentage of work orders with no work location specified	Low	Medium	High	If spare parts or other required material not is at the installation nor the base, unplanned shutdowns with short lead times will be difficult to utilize
Q3	Number and percentage of work orders with no material received at installation or base	Low	Medium	High	If many work orders are missing work location, work description or work scope challenge, unplanned shutdowns with medium lead times will be difficult to utilize opportunistically
Q4	Number and percentage of work orders with no description of work to be carried out	Low		High	
Q5	Number and percentage of work orders with no WSC performed	Low		High	
V1	Amount and percentage of man-hours per user status	Many RDEX	Many PRCO	Many PREP	If the number of work orders and amount of man-hours in PREP phase is low, unplanned shutdowns with medium lead times will be difficult to utilize opportunistically.
V2	Number and percentage of work orders per user status	Many RDEX	Many PRCO	Many PREP	If the number of work orders and amount of man-hours in RDEX phase is low, unplanned shutdowns with short lead times will be difficult to utilize
V3	Number and percentage of work orders with system status created & released	Many REL	Many REL	Many CRTD	If the number of work orders in REL phase is low, even unplanned shutdowns with long lead times will be difficult to utilize opportunistically

Figure 12 Indicators for shutdown preparedness monitoring

The lagging indicators measures if, and to what degree maintenance opportunities are utilized. These are utilization indicators

Indicator	What is measured	Why interesting
U1	Number of work orders completed and man-hours carried out during unforeseen shutdowns	Measures whether or not unforeseen shutdowns have been utilized opportunistically, and the volume of work carried out
U2	Utilization degree or the percentage of man hours carried out during unforeseen shutdowns relative to man-hours theoretically available	Measures how much of the available time that has been used opportunistically, totally as well as split on shutdowns with short, medium and long lead times

Figure 13 Indicators for Shutdown utilization, lagging indicators

3.9 Scorecards

The top level management has historically relied more or less entirely on financial measures for the performance of operations in their company. As mentioned it is well-known that this is not sufficient in order for a company, business are or department to be driven in the most efficient manner, as *these measures can give misleading suggestions for continuous improvement and innovation, and are out of step with the skills and competencies needed by today's organization* (Maltz, Shenhar, & Reilly, 2003). The balanced scorecard is an approach applied to establish a maintenance performance measurement system. There exist other similar systems, such as Du Pont Pyramid, SMART Pyramid and Cambridge PM Process, but the Balance Scorecard leads in this development.

> *The Balanced scorecard is a strategic planning and management system that is used extensively in business and industry, government, and non-profit organizations worldwide to align business activities to the vision and strategy of the organization, improve external and internal communications, and monitor organization performance against strategic goals.*
> (Balanced Scorecard Institute)

The Balanced Scorecards goal is to give the top management a more "balanced" view of organizational performance. In addition to its financial perspective, they will by applying the Balanced Scorecard have non-financial measures for performance. As a multi-dimensional framework it also helps the tactical division identify what should be done and measured – i.e. actions are performed in accordance to the given strategies of the organization (Thorstensen, The Role of Key Performance Indicators (KPI's) in Maintenance Performance Measurements, 2008).
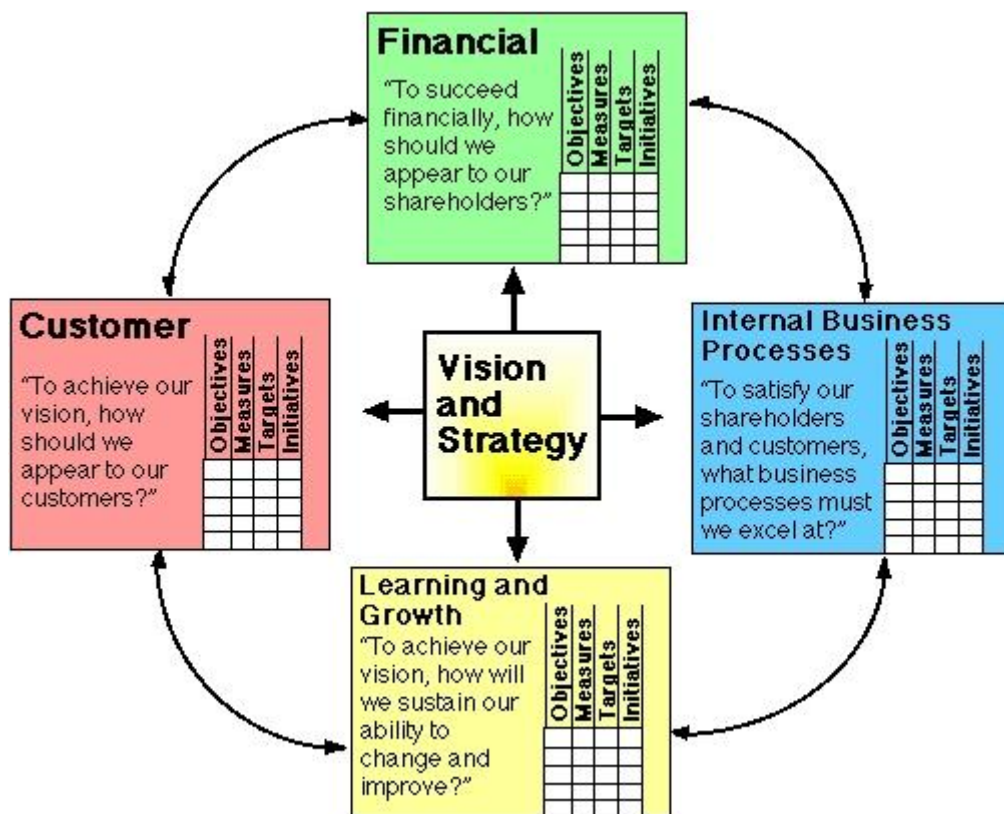

Figure 14 the balanced scorecard (Balanced Scorecard Institute)

As seen from Figure 12 the Balanced Scoreboard consists of four perspectives, upon which metrics is to be developed and data to be collected and analysed from.

3.9.1 Financial

Financial improvements are the foundation for any sustainable development of a company, and can't be neglected. An example is that *maintenance activities are carried out in a cost-effective manner* (Thorstensen, 2008)*.*

3.9.2 Customer

According to the balancedscorecard.org recent management philosophy has shown increasing realization of the importance of customer focus and customer satisfaction in any business. A customer objective could be *to do our utmost to deliver what we promise to each other, to our shareholders, and society at large.* (Thorstensen, 2008)

3.9.3 Internal business processes

Metrics from this perspective shows the managers how well their business is running, and if its products and services conform to customer requirements. Ex.: *backlog holds no safety critical job*. (Thorstensen, 2008)

3.9.4 Learning and growth perspective

This perspective includes employee training and corporate cultural attitudes related to both individual and corporate self-improvement. In a company with specialized expertise the people are a vital resource, and they need to be in a stimulating environment. In addition to this stimulating environment and communication, it also includes technological tools – or "high performance work systems". *Our employees are competent and motivated.* (Thorstensen, 2008)

The scorecard differs from traditional performance measurements systems, which often specify the particular action they want employees before they measure these actions. Instead of this control measurement, the scorecard puts strategy and vision in the center. The objective of the balanced scorecard method is to bring together the most important operational measures together in a single management report. This will give the managers a better foundation for making decisions and it will guard against sub optimization. That is, let the managers see if improvement in one area may have been achieved at the expense of another (Kaplan and Norton, 1992).

3.10 Microsoft Access

In the Turnaround & Shutdown Optimization report one find a procedure for calculating the indicators manually in Microsoft Excel. However, it can be argued for that Microsoft Access can do this job better. The thought is to systematize the large amount of data from the week dump, so that the calculation of the indicators can be done more effectively. By extracting the data from Excel to Access a database is created. A so called Query in Access would presumably be more appropriate for this task than the Pivot tables created and used in Excel.

Microsoft Office Access, previously known as Microsoft Access, is a relational database management system (RDBMS) from Microsoft that combines the relational Microsoft Jet Database Engine with a graphical interface and software-development tools (Wikipedia). This system is based on the relational model introduced by E.F. Codd in his paper "A Relational Model for Large Shared Data Banks". A short definition of an RDBMS from Wikipedia is:

> *An DBMS in which data is stored in tables and the relationships among the data are also stored in tables. The data can be accessed or reassembled in many different ways without having to change the table forms.(Wikipedia.com/RDBMS*

As Excel is spreadsheet software, the database management system Access has its advantages for this particular case. The current data is stored in 4 sheets per week, which basically means relational data. Both Excel and Access can run powerful queries to sort and filter data, but here Access by its relational tools makes the process easier. There are other great advantages as well. If it is desirable to continue the queries furthermore, Access will simplify this too. The queries in Access are dynamical, as the instructions and not the results are saved, in case of adding more tables (weeks). Having to consider a large amount of data (thousands of entries) and as the criteria's are increasing, Access should under equal circumstances work faster, i.e. be able to handle more data.

And in a commercial view Access offers both Forms that are meant to be user friendly and Data Access Pages for the more technical user. (Access 2010)

4 Method: Query Example, Microsoft Access

The scope of the work done by performing the queries performed in Microsoft Access based on the indicators given should be documented. Prior to the actual queries, the week dump was to be categorized. The raw data consisted of 4 work sheets per week, Work Orders, Operation, Material and Work Permit (see appendix). It is anticipated that the best way to do the queries, is to merge all the work order sheets in one sheet, all operation sheets in one sheet, etc.

After the database has been created from the week dump and extracted into MS Access, the queries can be performed. For each indicator follows one query. In MS Access a Query Wizard is used, which allows the user to select relevant parameters from the relevant database. 4 databases per installation are created, Work Orders, Operation, Material and Work Permit. After selecting the parameters, the queries can start.

As seen from Figure 17, we are here separating between OK and not OK man-hour estimations. In order to get to that particular result, number of shutdown Work Orders are first to be found. This is a simple operation where one database, Work Orders, is used to find the orders marked as Shutdown WO in the Work Scope Challenge status description. As seen from the graph the No. of WO's with shutdown in week 20 for Installation A is 78. In the Query of current investigation, Q1, the goal is to sort out WO's with one or more operations containing man-hour estimations less than one. The man-hour information derives from another database, Operation.
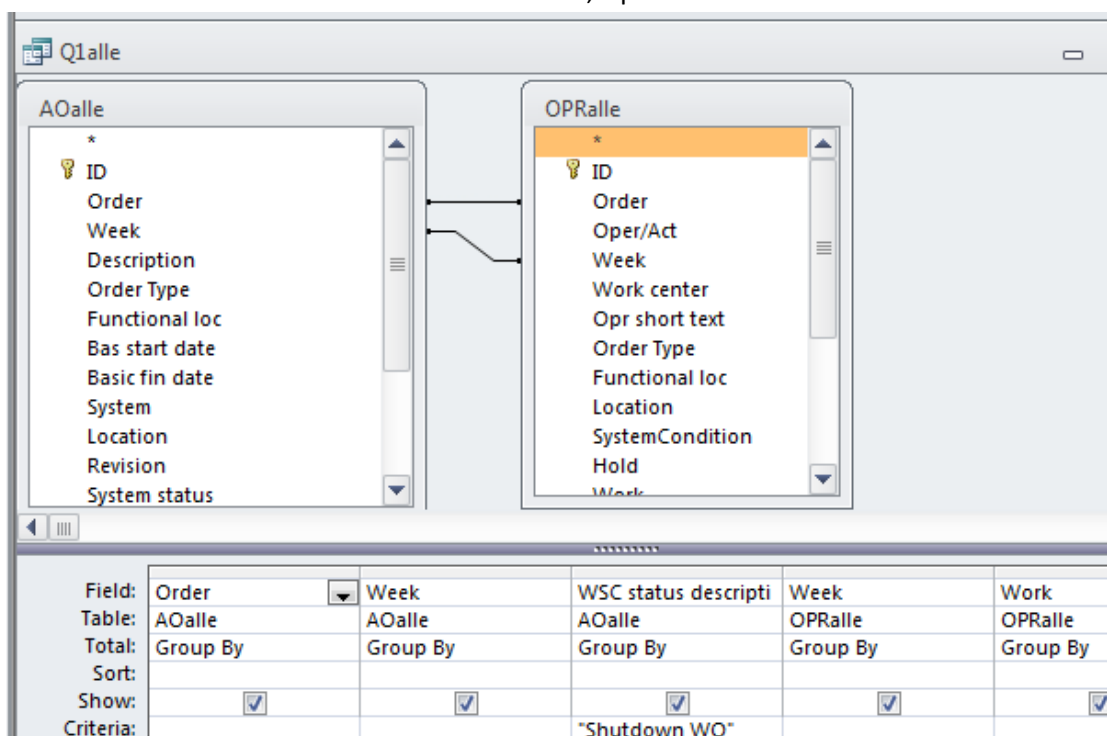

Figure 15 Joint properties example

This is where MS Access shows some of its potential, by using Joint Properties in linking two databases together, as shown in Figure 15. The user now is given the possibility to extract data from one database, considering whether or not it matches the current criteria for both of the databases. Running the query at this point will give the user all shutdown related work orders, with existing man-hour estimations. By filtrating man-hour estimations less than one, marked as "work" in the week dump, the number of shutdown work orders containing man-hour estimations less than one,

Q1, is found. A note to the user of Custom Filtrating in Access is to filter for less than 0.99, as less than 1 will include work orders equal to 1.

Order	AOalle.Wee	WSC status descrip	OPRalle.We	Work
20855317	20	Shutdown WO	20	0
20919244	20	Shutdown WO	20	0
21020530	20	Shutdown WO	20	0
21020531	20	Shutdown WO	20	0,5
21020532	20	Shutdown WO	20	0,5
21113074	20	Shutdown WO	20	0
21113075	20	Shutdown WO	20	0
21445673	20	Shutdown WO	20	0
21450552	20	Shutdown WO	20	0
21468948	20	Shutdown WO	20	0
21474379	20	Shutdown WO	20	0
21504437	20	Shutdown WO	20	0
21517097	20	Shutdown WO	20	0
21517786	20	Shutdown WO	20	0,5
21529725	20	Shutdown WO	20	0
21552376	20	Shutdown WO	20	0
	16			1,5

**Figure 16 Filtrating example MS Access**

The result is displayed as shown in Figure 16. In week 20 there are 16 shutdown related work orders containing work-hour estimations less than 1. By sorting out the same data for each week and comparing with the total amount of shutdown related work orders, the first Quality indicator Q1 is found.

For Query 1 the procedure explained is to be performed for weeks 20 – 39. For the Volume indicator V5 on the other hand, the process is more time consuming. This indicator asks of number of work orders per order type. We are separating between 5 different order types. Furthermore installation B consists of 3 installations treated separately. This altogether makes Query V5 the largest and most time consuming of the indicators, existing of 204 unique sums.(Figure 56).

From the report T&S Optimization, A.3 – Shutdown Preparedness, we have the results from the measurements performed by the previous described group from Statoil and IBM. In this report the measurements will be continued from week 20 – 39. For the breadth of view both the results for week 7 – 20 and 20 – 39 are presented beside each other.

Due to confidentiality these installations are referred to as Installation A and B. There is a need for confidentiality as this is sensitive material and may be used against Statoil in one way or another.

## 4.1 Q1 – Work orders with one or more operations containing man-hour estimations <1. Installation A
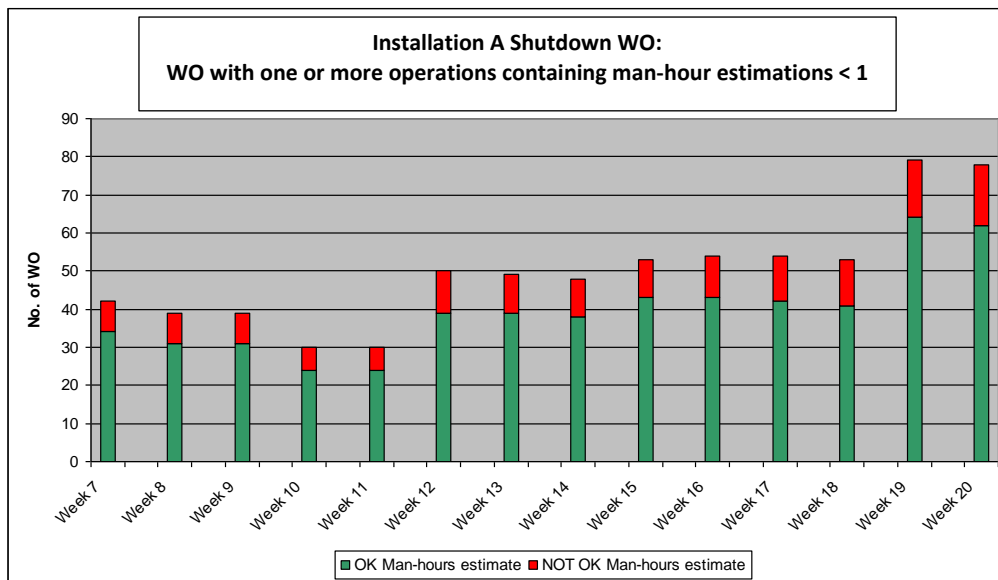
Figur 17 Q1-A (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
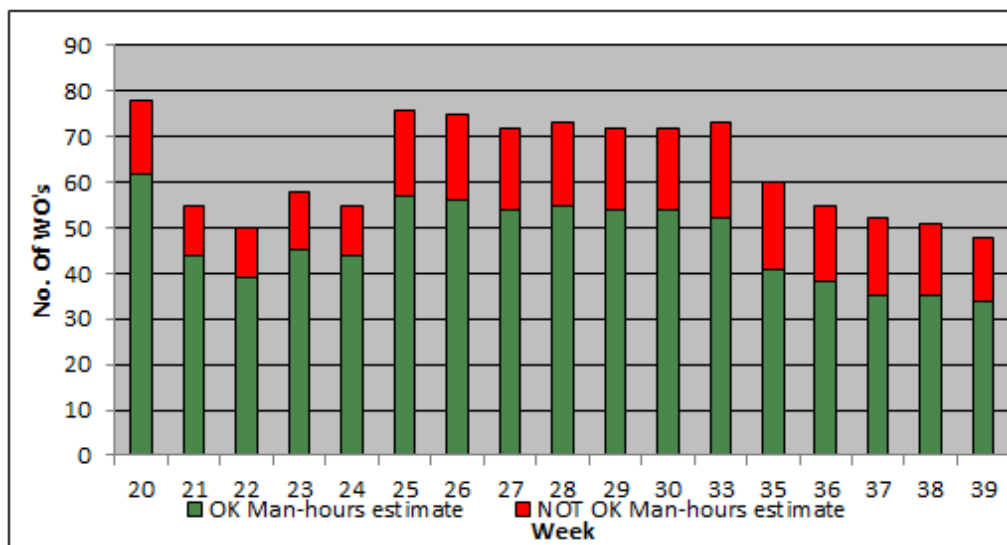
Figur 18 Q1-A

From Installation A the fraction of bad orders is decreasing for the first measurement period, which is expected to be an adequate indicator. Measuring until week 39 gives another picture of what is actually happening. We see that the fraction of bad orders is increasing in week 21-24, before decreasing again from week 25-33, until it finally increases towards week 39. The fraction is changing, but the number of bad WO's stays relatively the same. Many of the bad WO's are found in in several weeks. This is verified by going through the queries after making the table.

4.2 Q1 – Work orders with one or more operations containing man-hour estimations <1. Installation B
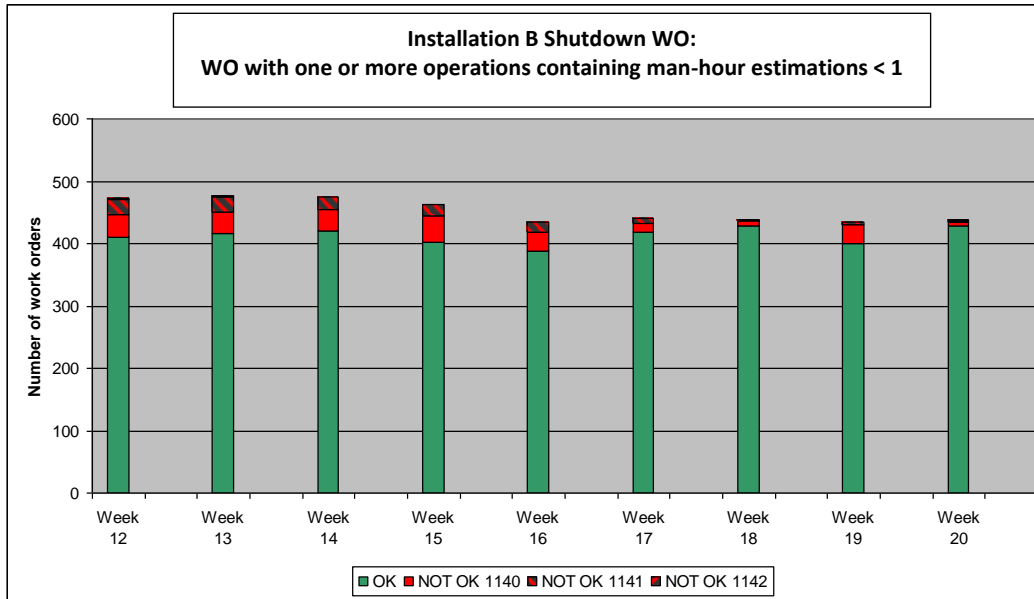
Figur 19 Q1 – B (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
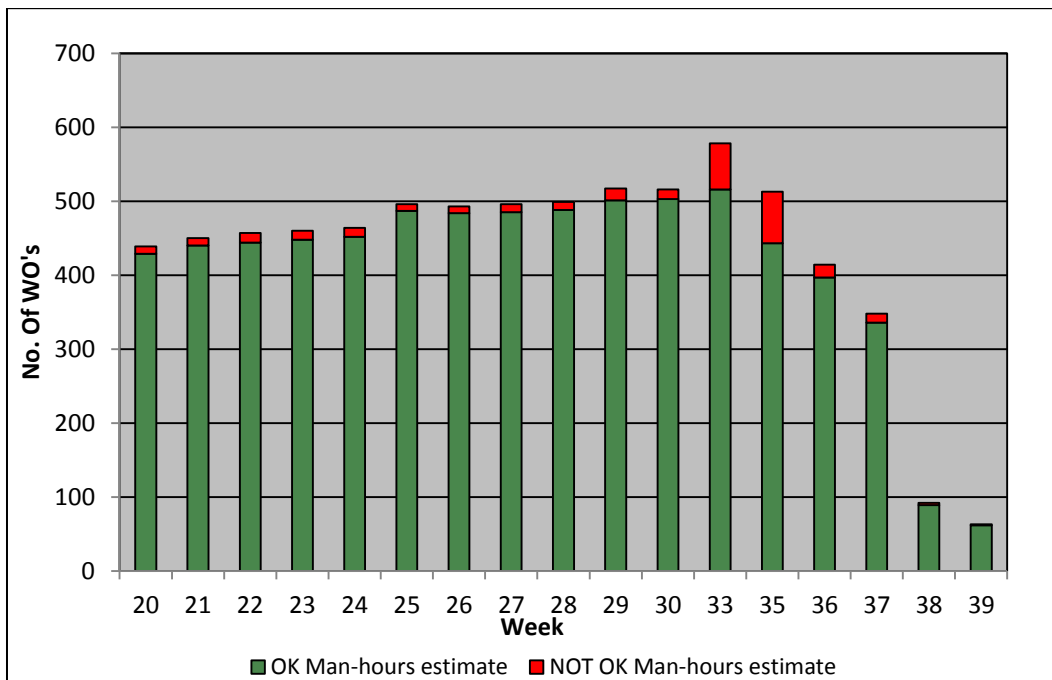
Figur 20 Q1 – B

The fraction of bad WO's is decreasing from Week 12 – 30, which again is expected to be an adequate indicator. In week 33 and 35 we see a sudden boost in bad WO's. Installation B had a turnaround from 16.8 – 7.9 and from 17.8 – 7.9, which was in weeks 33-36 (extracted from SAP). It is presumed that late orders without man-hours estimates have been reported in relation to this turnaround. The WO's are terminated, both ok and not ok, which is positive.

4.3 Q2- Location code exists on work order – Installation A
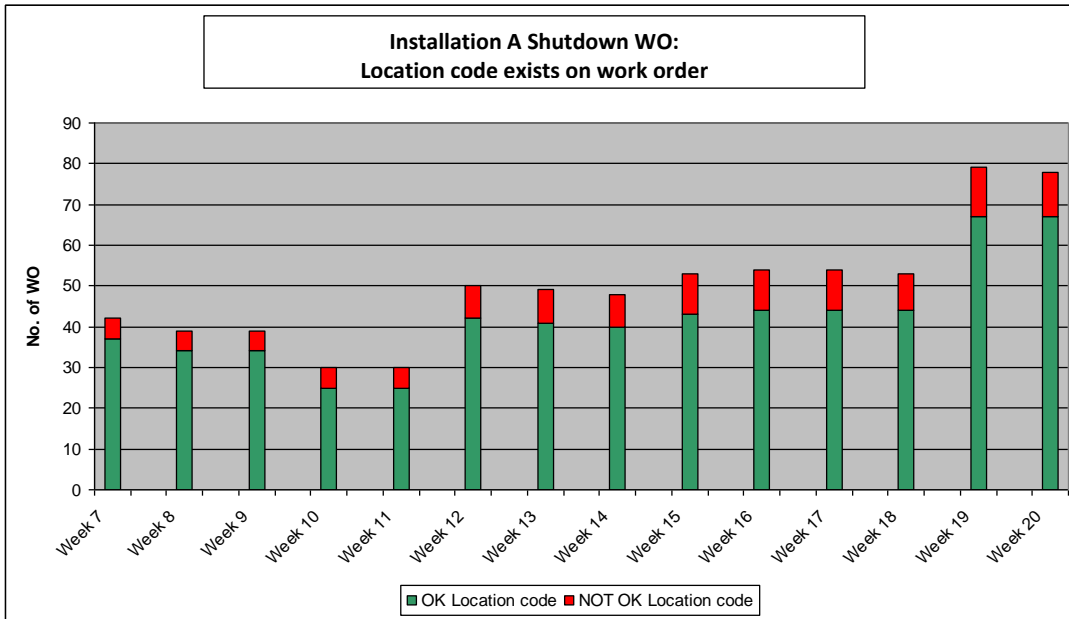
Figur 21 Q2 – A (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
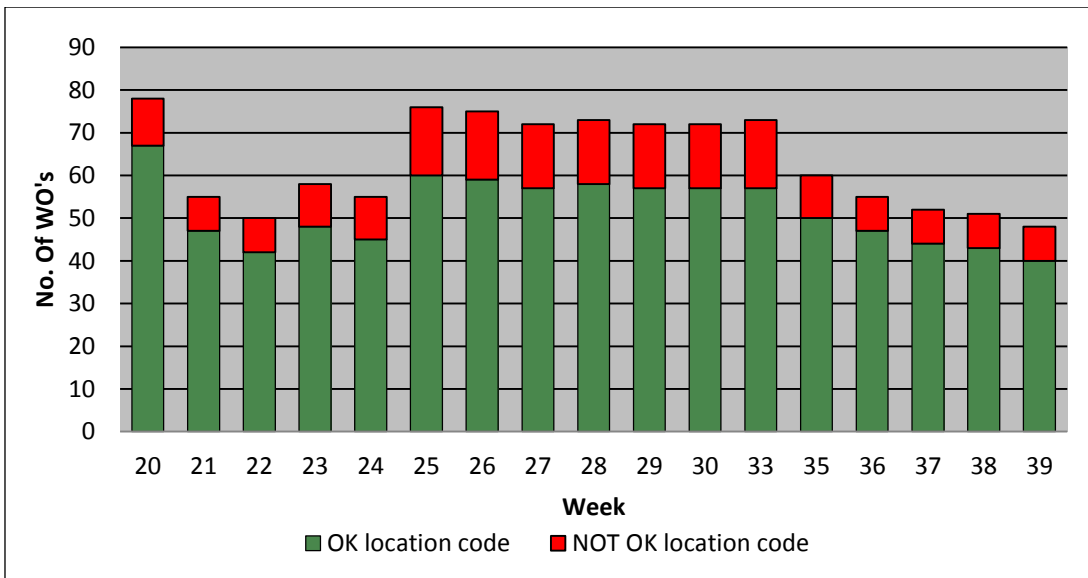
Figur 22 Q2 – A

Proper location code on the work orders is important in the planning perspective. The WO's should have a location code telling where the work order is to be performed. We can see that installation A has a decreasing fraction of bad location codes until week 21, in which the total amount of WO's are decreasing whereas the bad location codes stay the same. The number of bad location codes stays the same from week 35-36, during the shutdown, where they hopefully would've been terminated.

5.4 Q2- Location code exists on work order – Installation B

Installation B Shutdown WO:
Location code exists on work order
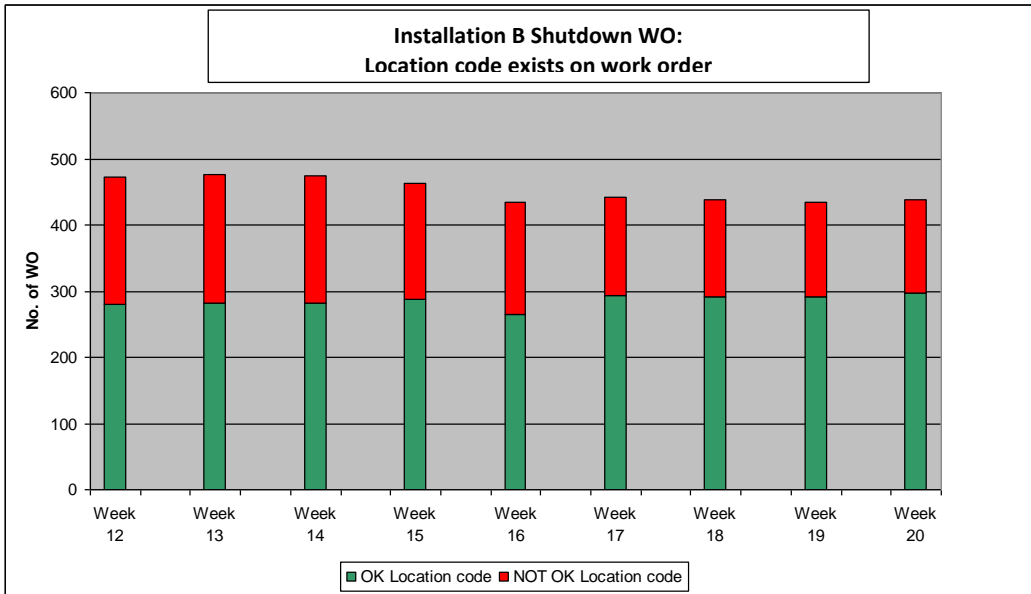
Figur 23 Q2 – B (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
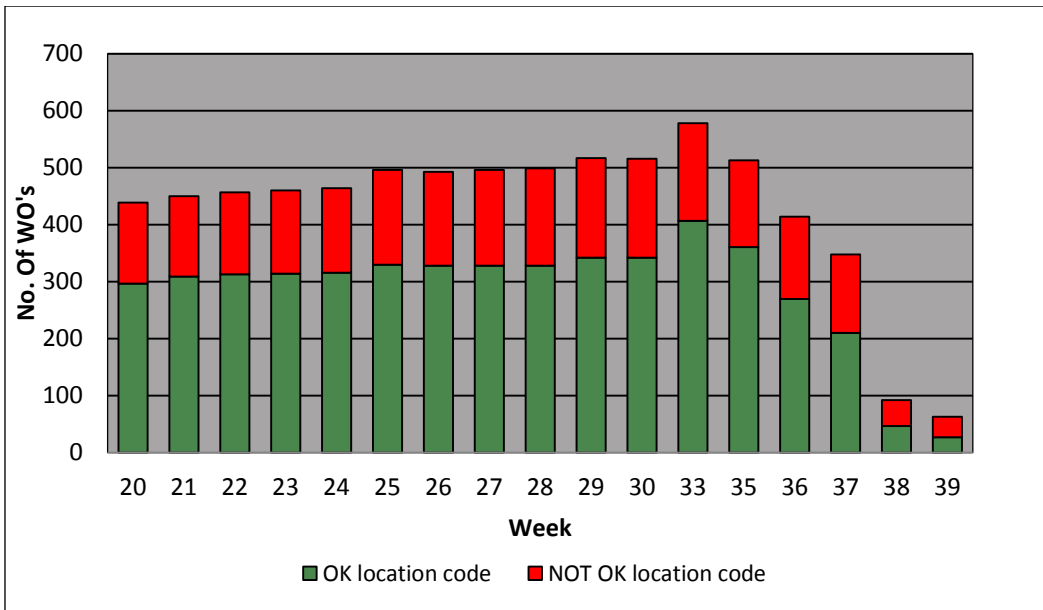
Figur 24 Q2 –B

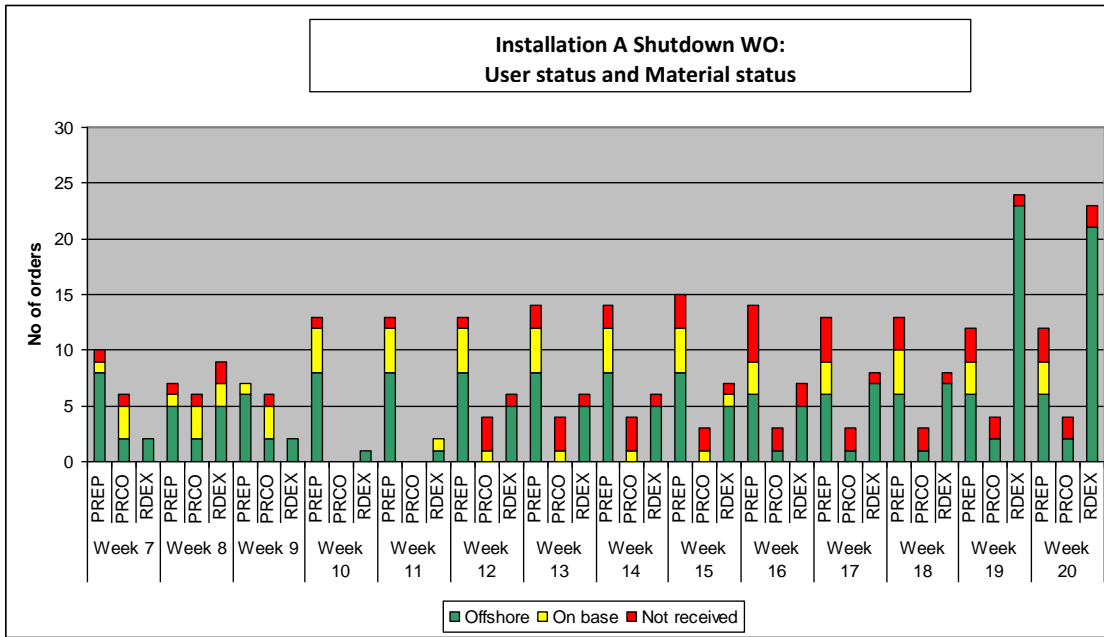The fraction of not ok location codes is stable high, especially if compared to installation A. During the shutdown the majority of both OK and Not OK WO's are terminated. Optimally all the bad WO's should be terminated, but some are still there after the turnaround.

4.4 Q3 – Material fully received on installation A

Figur 25 Q3 – A (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
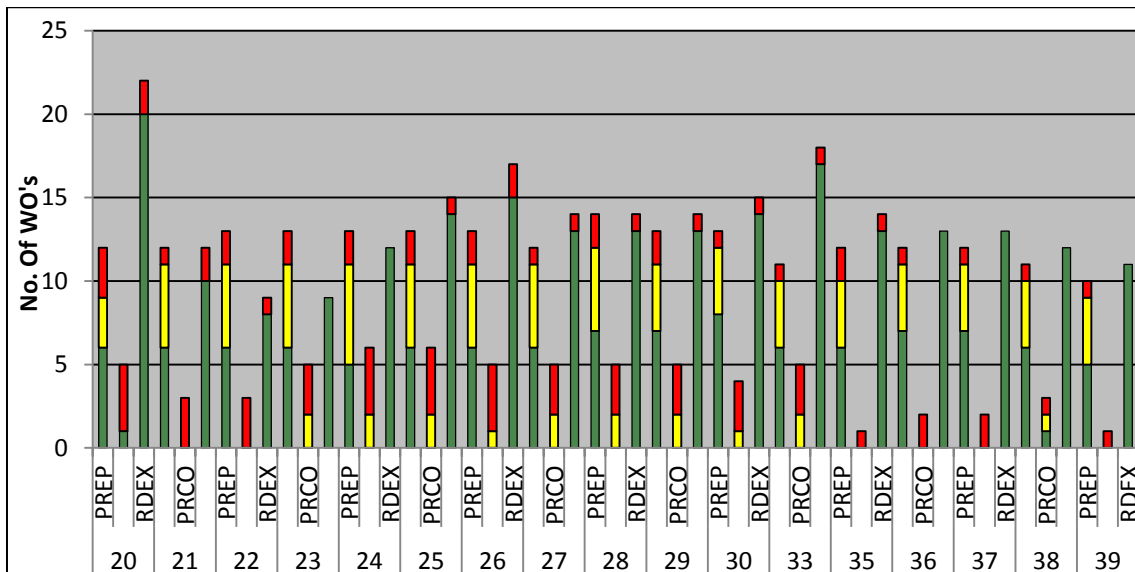
Figur 26 Q3 – A

User status and material status is important for utilization of opportunistic maintenance. If the planning horizon is short it's only possible to perform opportunistic maintenance if user status is RDEX (ready for execution) and all the material is located on the platform, or no material needed. For the plan able case (i.e. longer planning horizon) one could include the WO's in PRCO (preparation completed) with no material need or material stored on base onshore.

The fraction of material offshore is increasing for RDEX. This is positive and the opportunity to perform opportunistic maintenance in an unforeseen shutdown based on this indicator is impressive. There are all over few orders in PRCO, and the majority of these few are not received, so this doesn't provide much information.

4.5 Q3 – Material fully received on installation B

Figur 27 Q3 – B (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
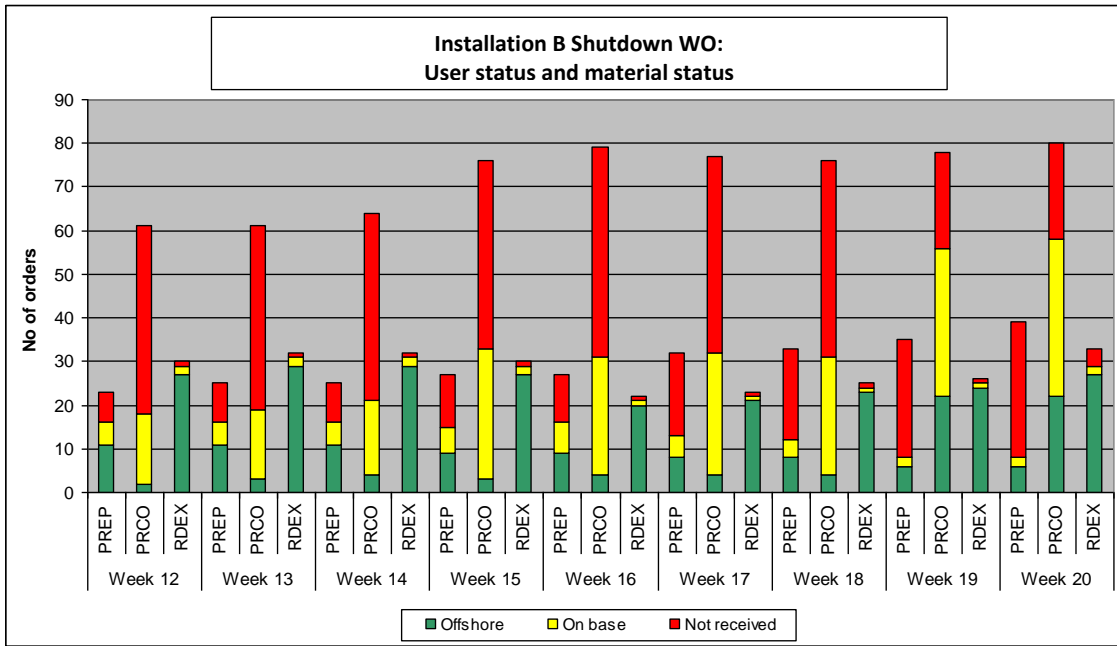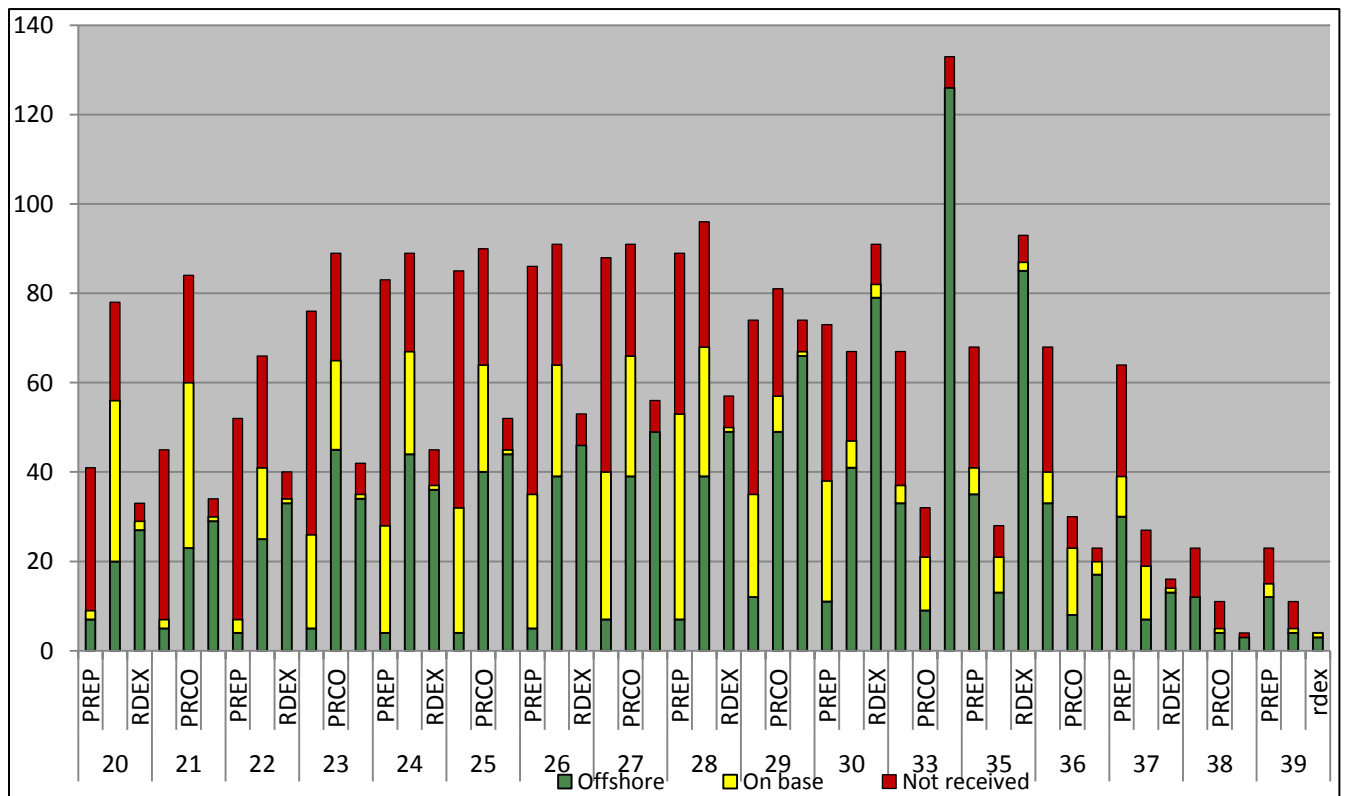

Figur 28 Q3 – B

The number of work orders offshore is constantly very high for RDEX, which is more that satisfactorily.

4.6 Q4- Short text on work order operations, installation A
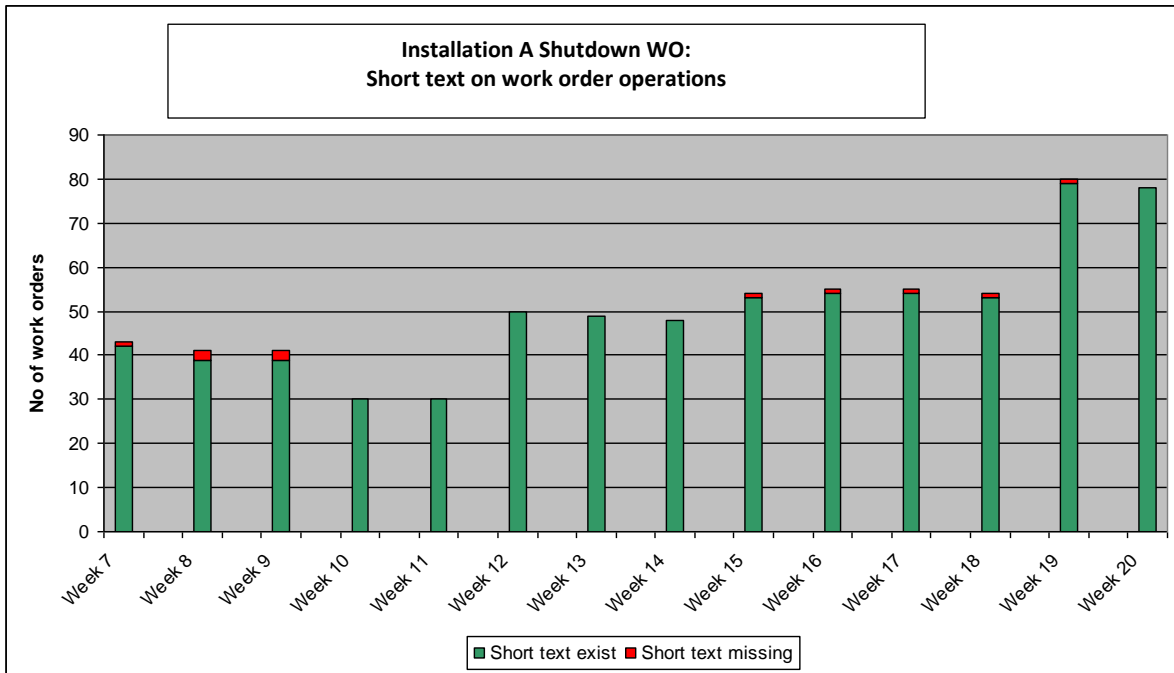
Figur 29 Q4 – A (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
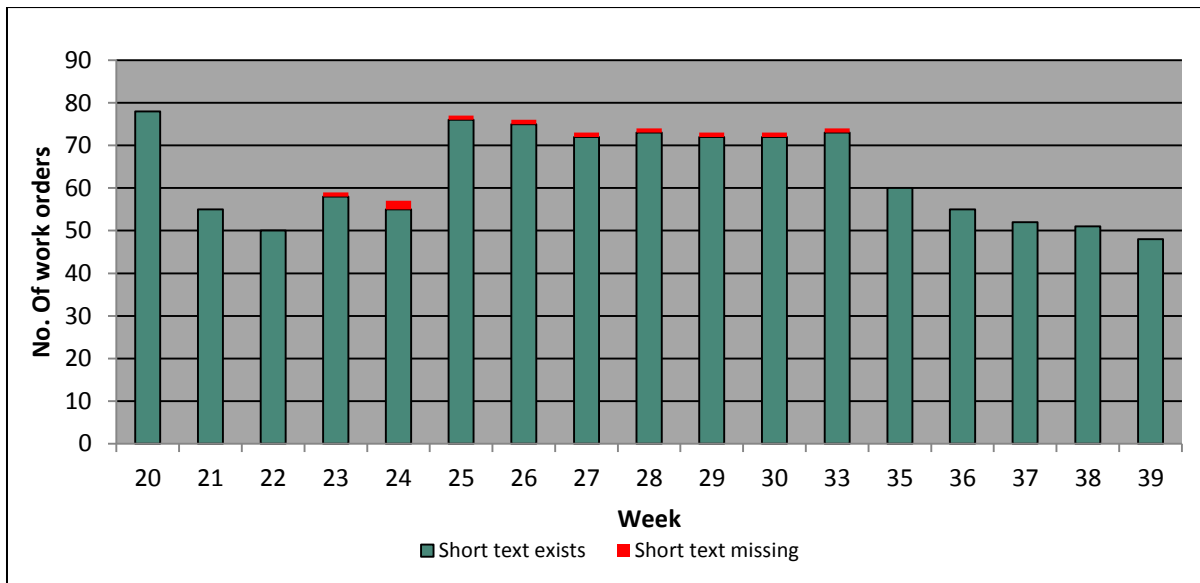
Figur 30 Q4 – A

If short text information is missing, it may be difficult for the scheduler to know exactly what to do. As shown in the figure there are hardly any WO's missing short text.

Q4- Short text on work order operations, installation B

Installation A Shutdown WO:
Short text on work order operations, B
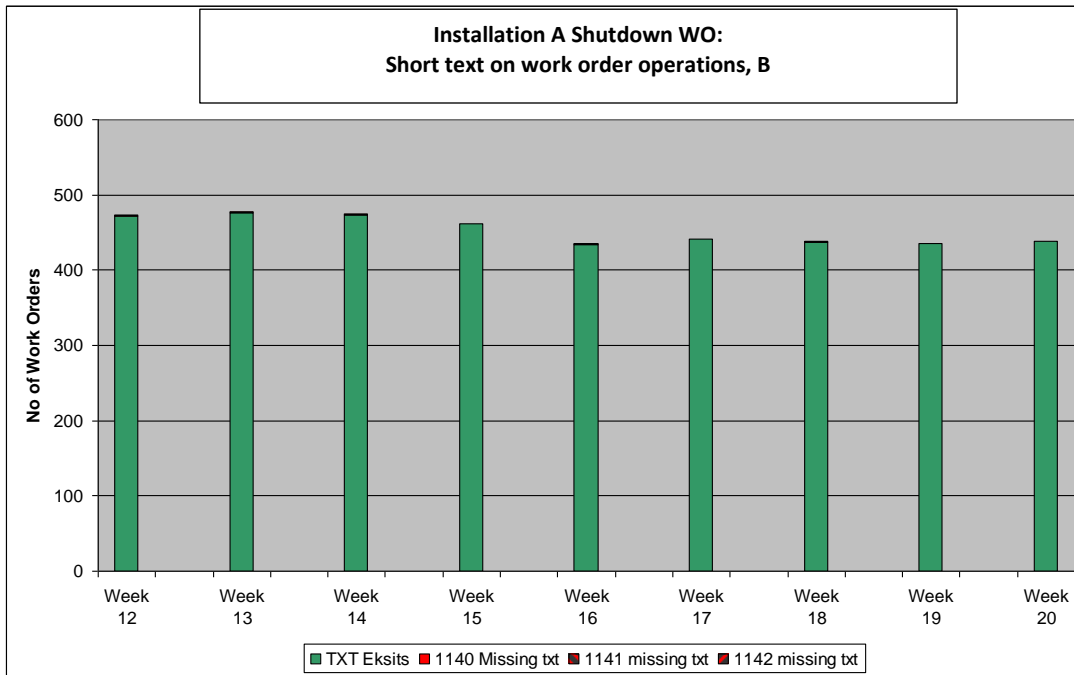
Figur 31 Q4 – B (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
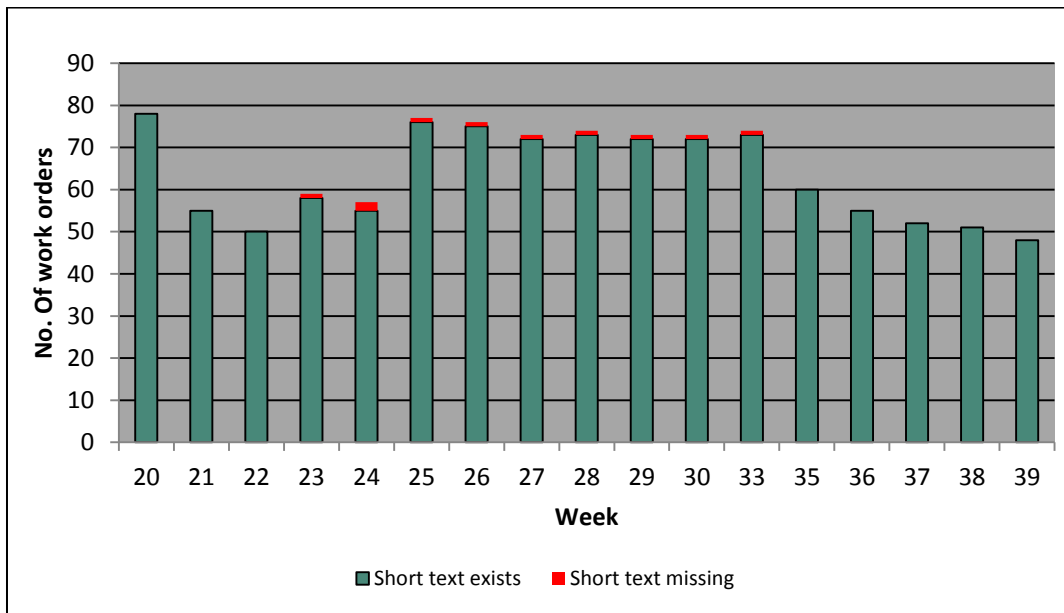
Figur 32 Q4 – B

For installation B the situation is the same – hardly any WO's are missing short text.

4.7 Q5- Work Scope Challenge (WSC) performed, installation A
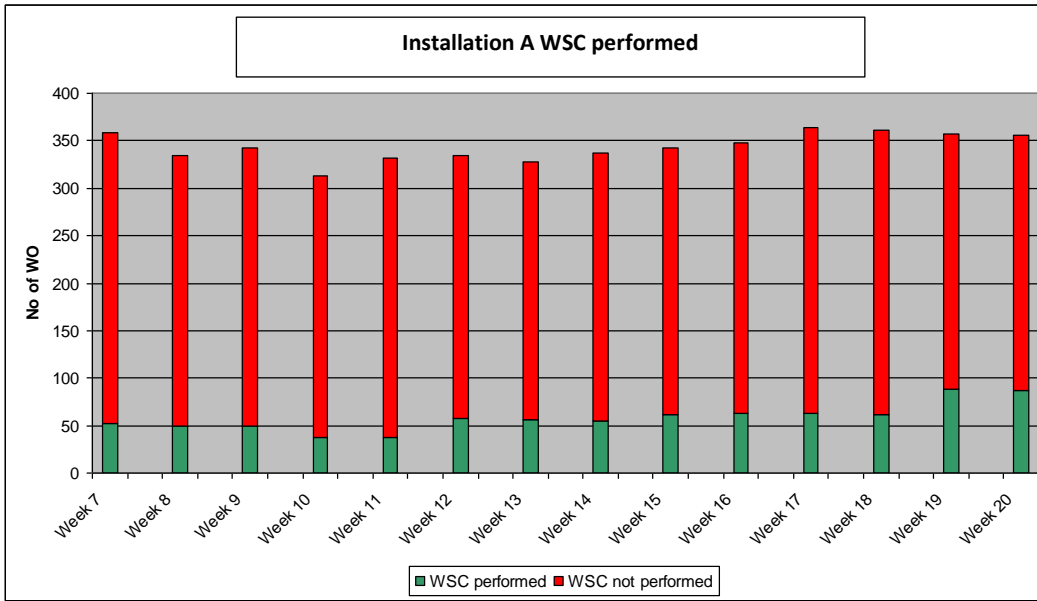
Figur 33 Q5 – A (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
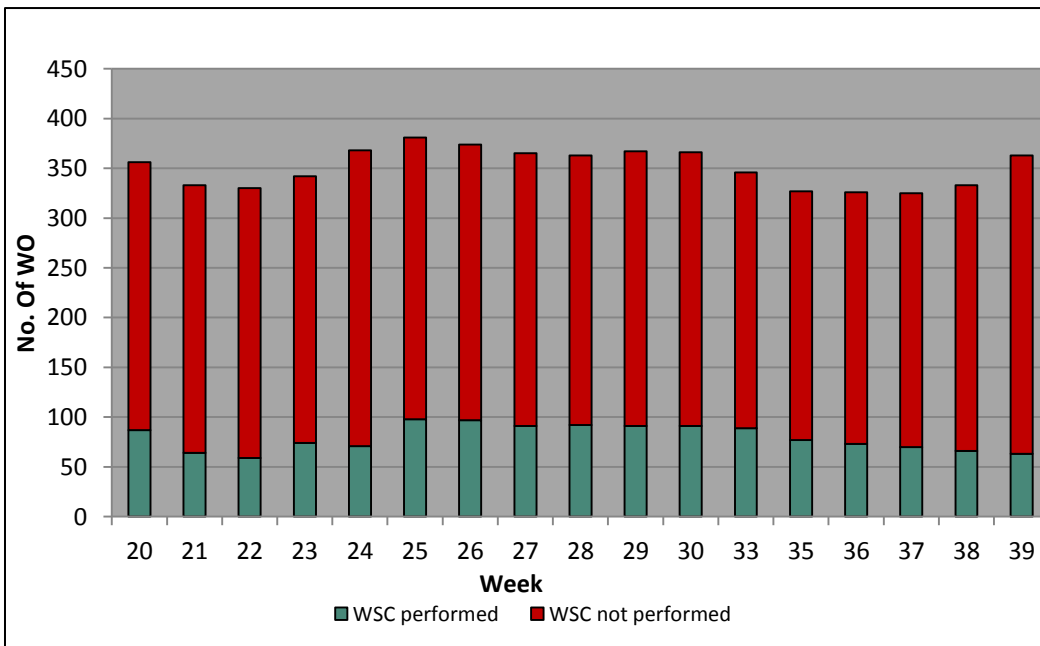
Figur 34 Q5 – A

The WSC performed indicator serves two purposes, as stated in the A.3 Shutdown Preparedness report. Both the fraction of WO's where WSC is provided, and the degree of following the work process in APOS. For installation A the fraction of WSC performed is low throughout the period, and is not satisfactory.

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4.8 Q5- Work Scope Challenge (WSC) performed, installation B
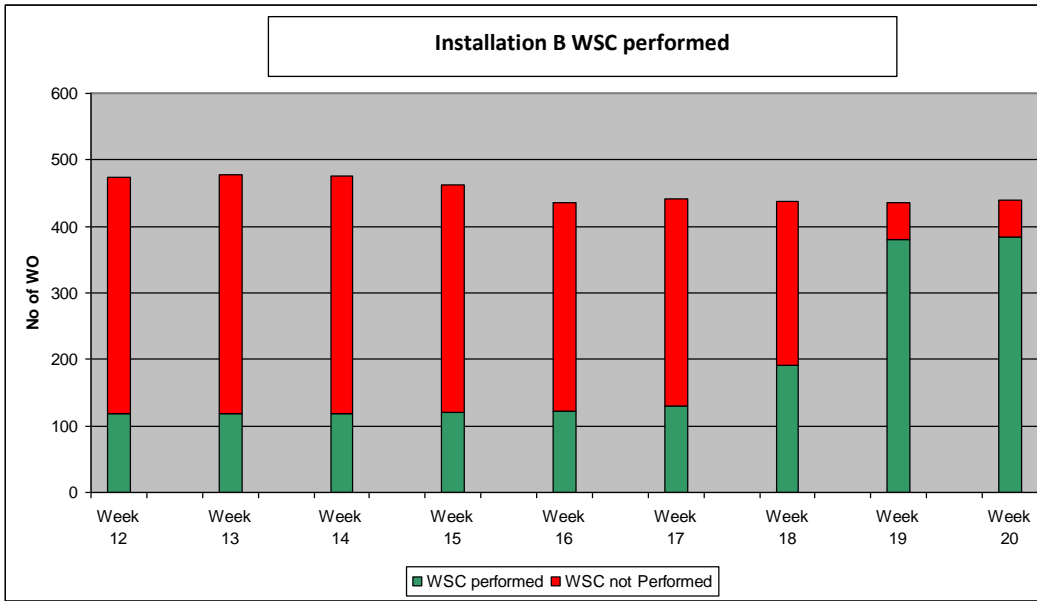
Figur 35 Q5 – B (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
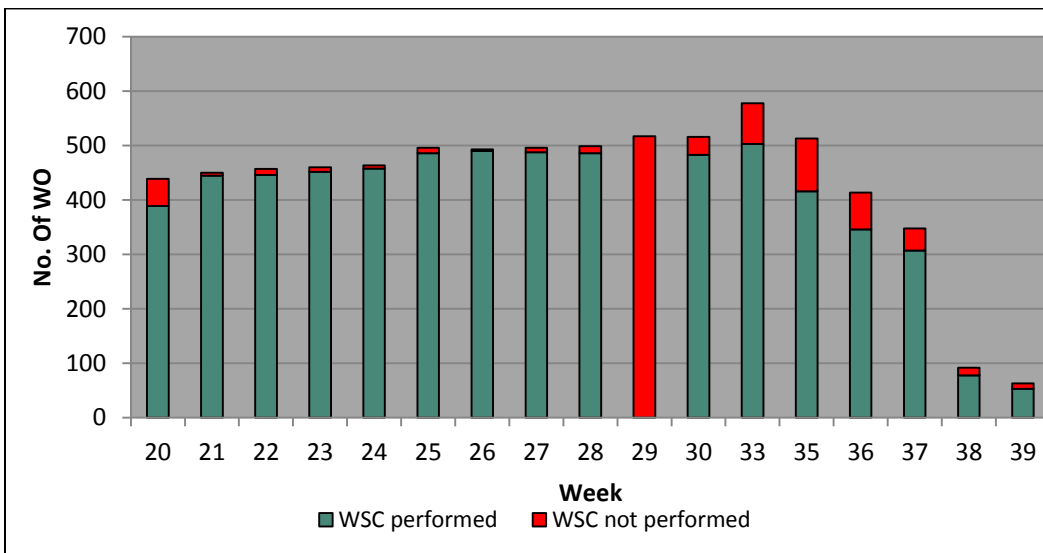
Figur 36 Q5 – B

For installation B a very positive trend can be seen from the graph. Until week 18 the fraction of WSC not performed is high, before almost every WO has WSC performed for the rest of the period. Week 29 has been investigated, and no activity on installation B that is known should cause this extreme case. The result shown is therefore considered to be a failure in the queries, as the rest of the data instantly seems "normal".

4.9 V1 - Man hours per user status, installation A
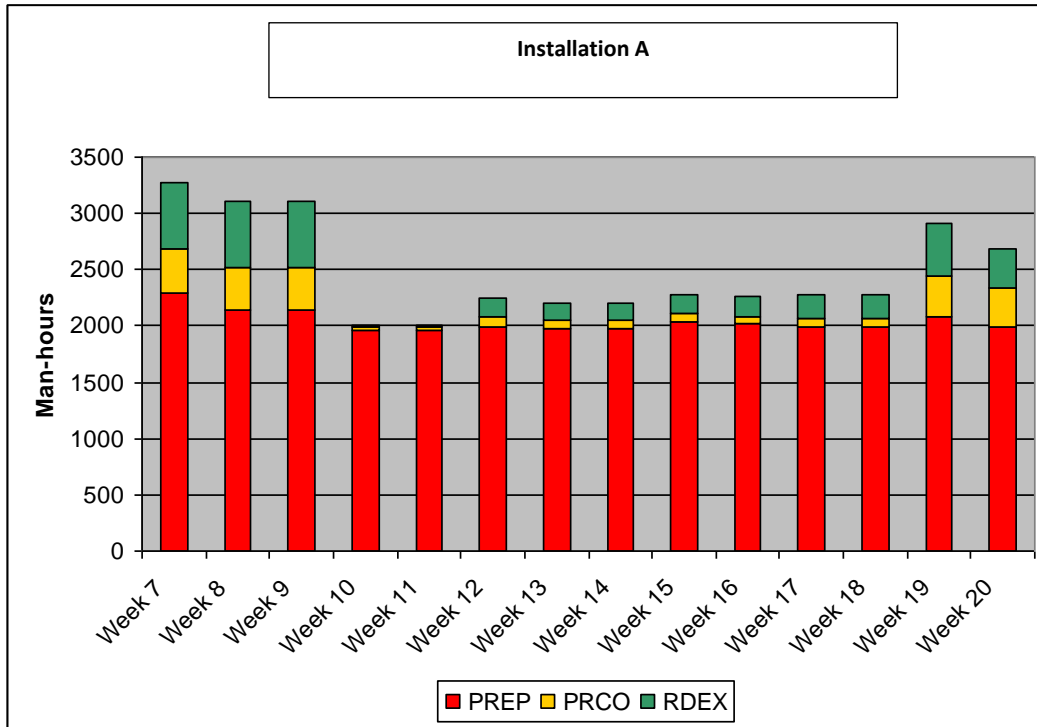
Figur 37 V1 – A (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
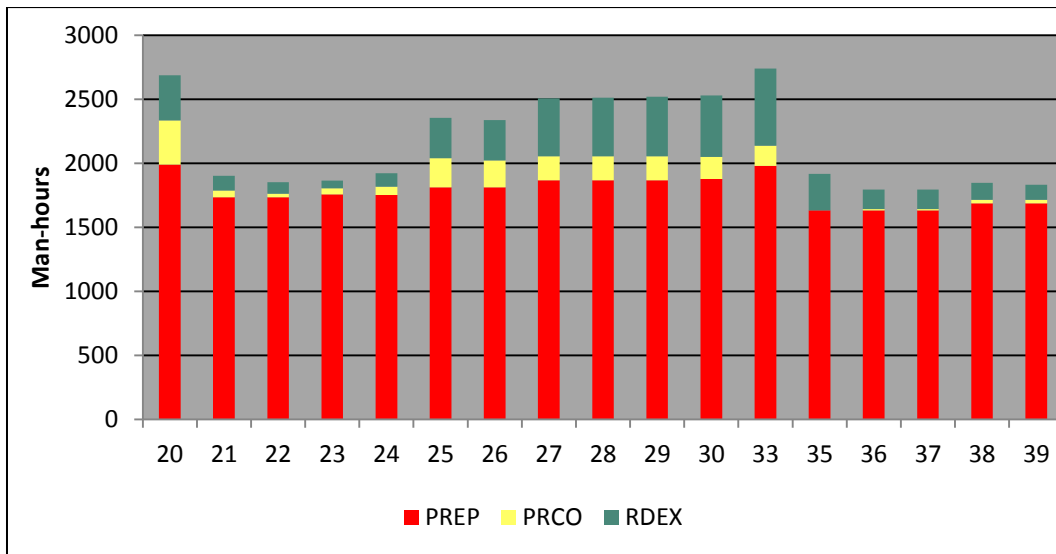
Figur 38 V1 – A

The user status (from SAP) shows the progress of the WO development according to the previous described work flow. The graphs show a high number and amount of PREP work orders. As explained earlier, only work orders in the RDEX category can be utilized in unforeseen shutdowns. Hence V1 for installation A is not satisfactory. Furthermore the considerable reduction in man-hours in RDEX in week 10 means shutdown work was carried out. The same can be seen in week 21 and 35.

4.10   V1 - Man hours per user status, installation B
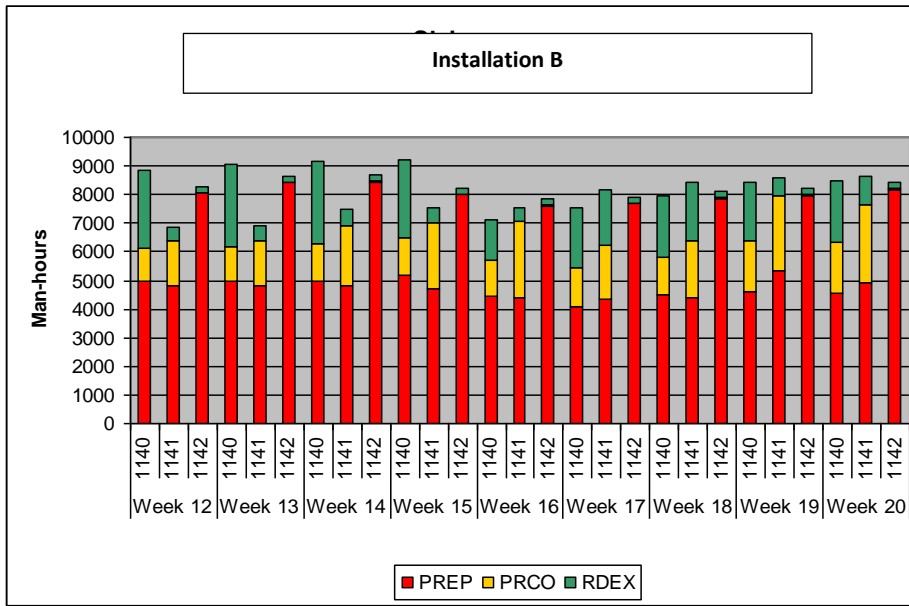
Figur 39 V1 – B (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
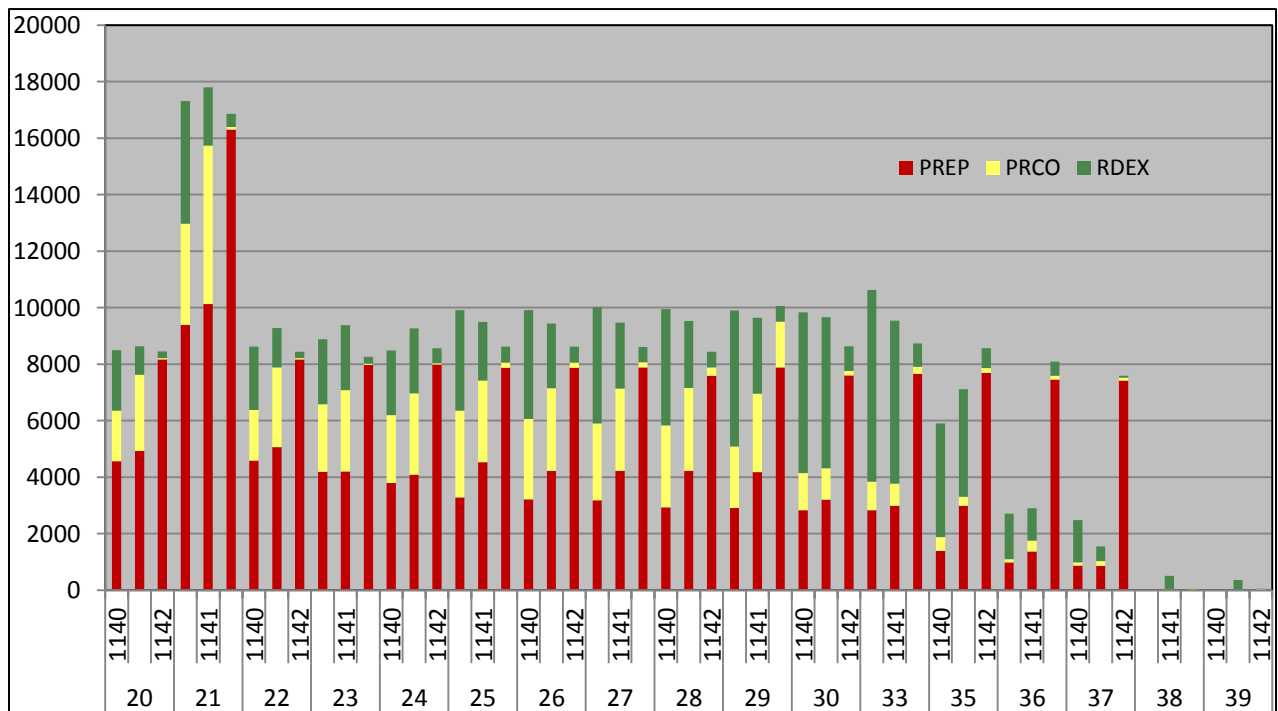
Figur 40 V1 – B

Also installation B has more work in PREP than in PRCO and RDEX.

"1142" sets apart from "1140" and "1141", by having almost only work orders in PREP. "1142" is an unmanned installation, which makes the utilization of opportunistic maintenance difficult without planning. In week 22 we see the numbers of WO's are reducing drastically, which indicates shutdown work was carried out. Also understood from the graph is that both "1140" and "1141" had shutdown work carried out in week 35, as the nr. Of WO's are reduced. The small increase in WO's in week 33 is also due to this shutdown. It is presumed the increase in week 34 would be even higher.

4.11 V2 – Number of work orders per user status, installation A

Installation A
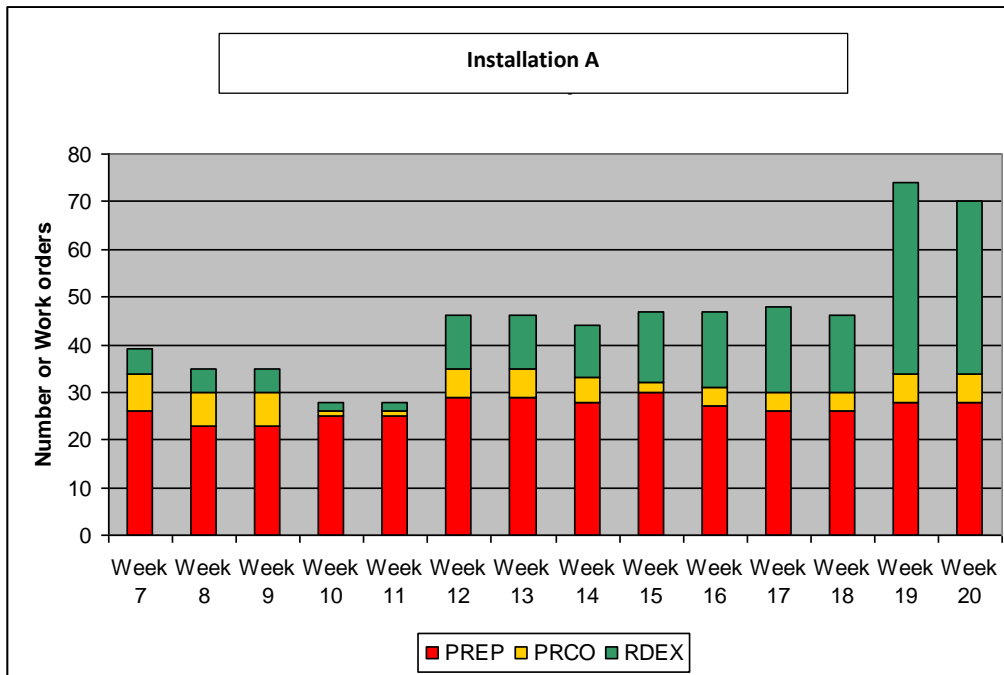
Figur 41 V2 – A (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
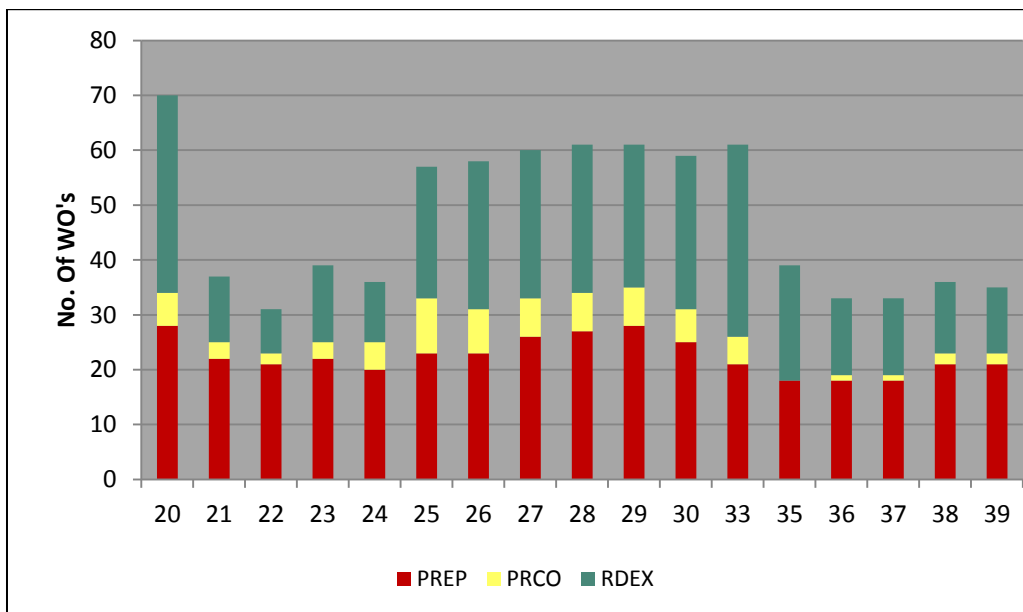
Figur 42 V2 – A

This indicator measures the number of work orders per user status, as opposed to man hours per user status as the case was in V1. The results from V1 and V2 should be analyzed with respect to each other. In week 39 there are about 10 WO's in RDEX and 20 in PREP. The connected number regarding man hours is 100 hours for RDEX and 1600 for PREP. It is known that the number of WO's and man hours for RDEX should be high to be satisfactory in the shutdown preparedness perspective. The results from V2 are thus a lot more positive than the ones from V1. As proposed in the A.3 Shutdown Preparedness report some work orders may demand more resources than others. The measurements performed here strengthen that theory.

4.12   V2 – Number of work orders per user status, installation B
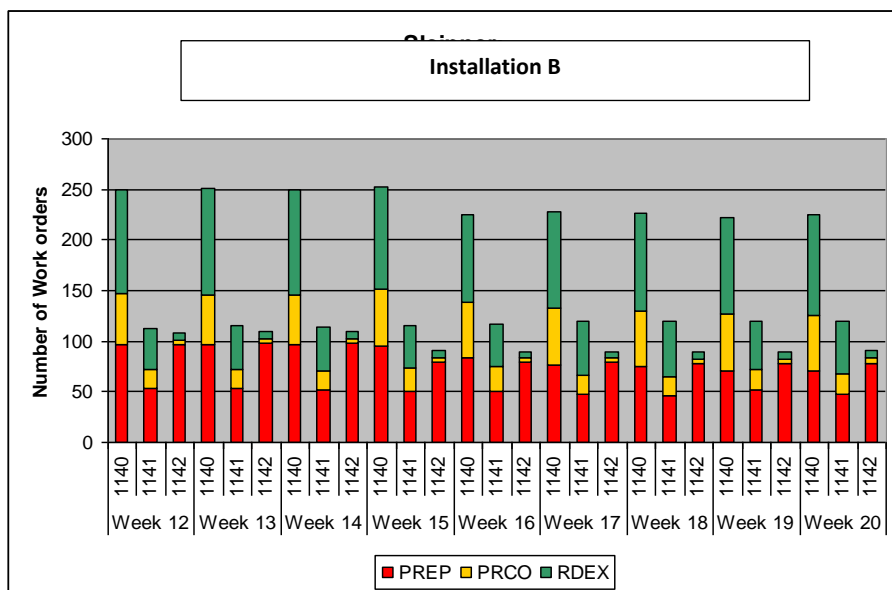
Figur 43 V2 – B (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
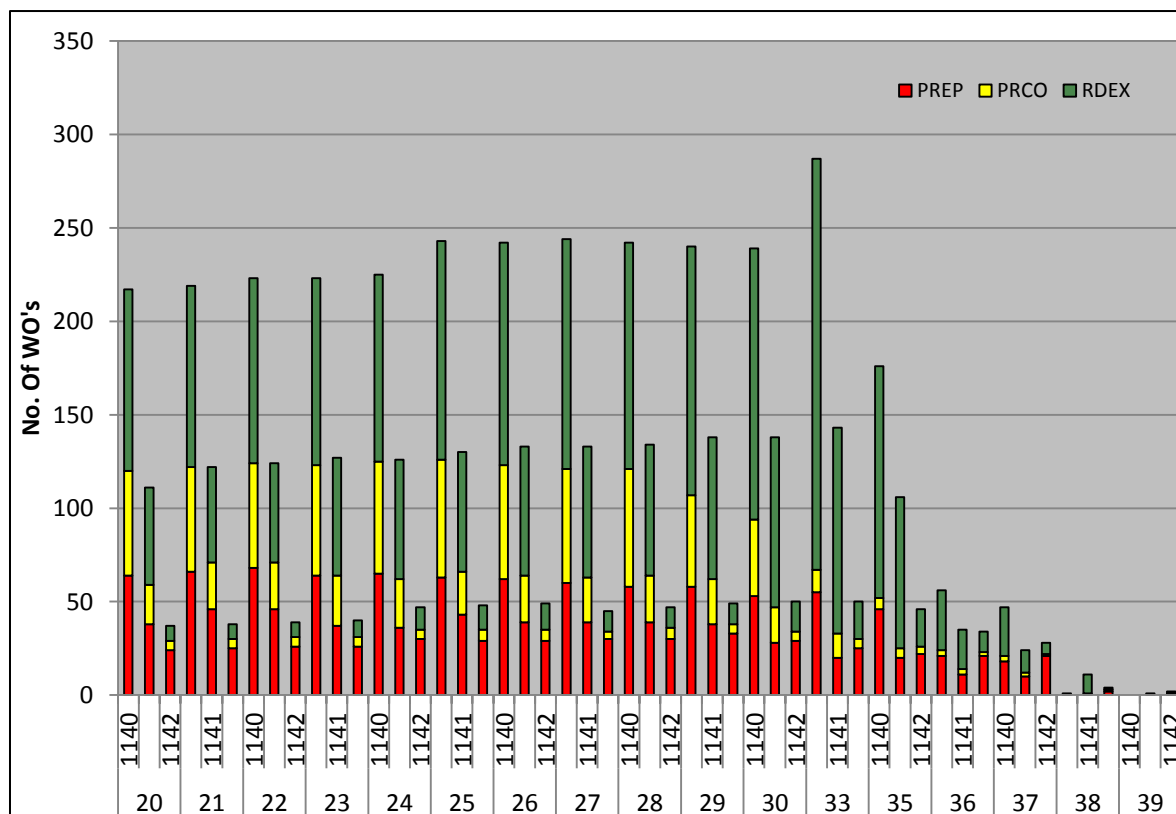
Figur 44 V2 – B

For "1140" there is a very similar situation as described for installation A. The number of WO's in PREP is about one fourth of all the WO's for this unit, whereas the fraction it earlier (regarding to man-hours) was much higher. Again, V2 shows better prospects for utilizing shutdown opportunistically than V1. The case for "1142" is alike the measurements for V1, as almost all the WO's are in PREP, making unplanned shutdowns hard to utilize.

4.13 V3 – Work orders per created or released, installation A
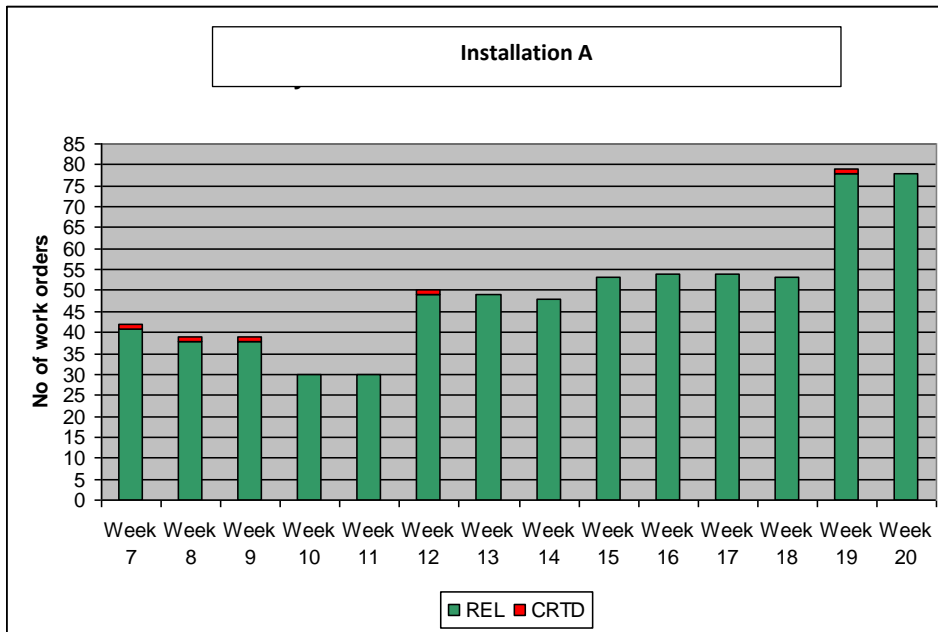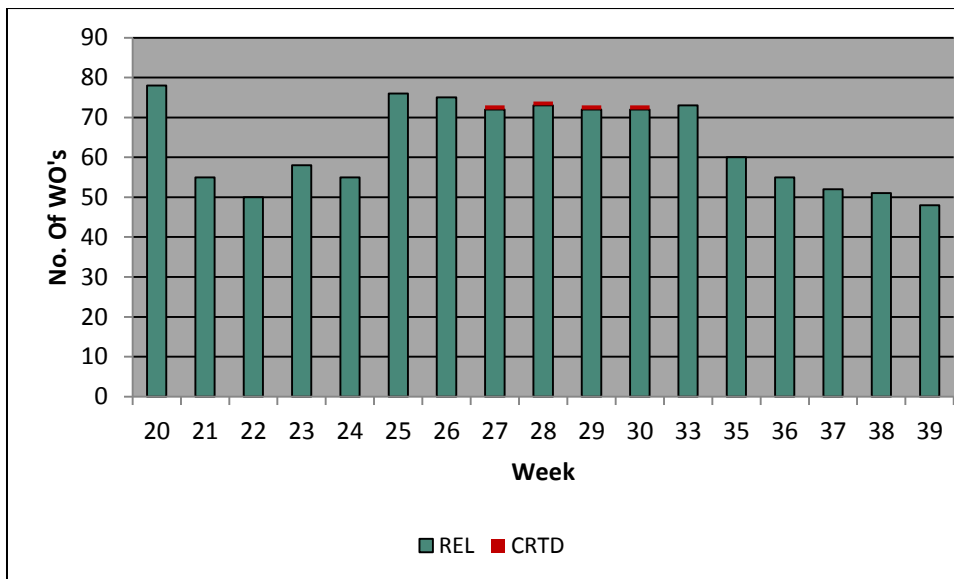
Figur 46 V3 - A

A work order has to be released before executed. Prior to the release, the work has to be subject to quality assurance. This indicator seeks to follow up that no shutdown work is held up because of a missing "release". (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)

Figure 45 and 46 shows that installation A has very few WO's in CRTD, making the shutdown preparedness satisfactory for this indicator.

4.14   V3 – Work orders per created or released, installation B
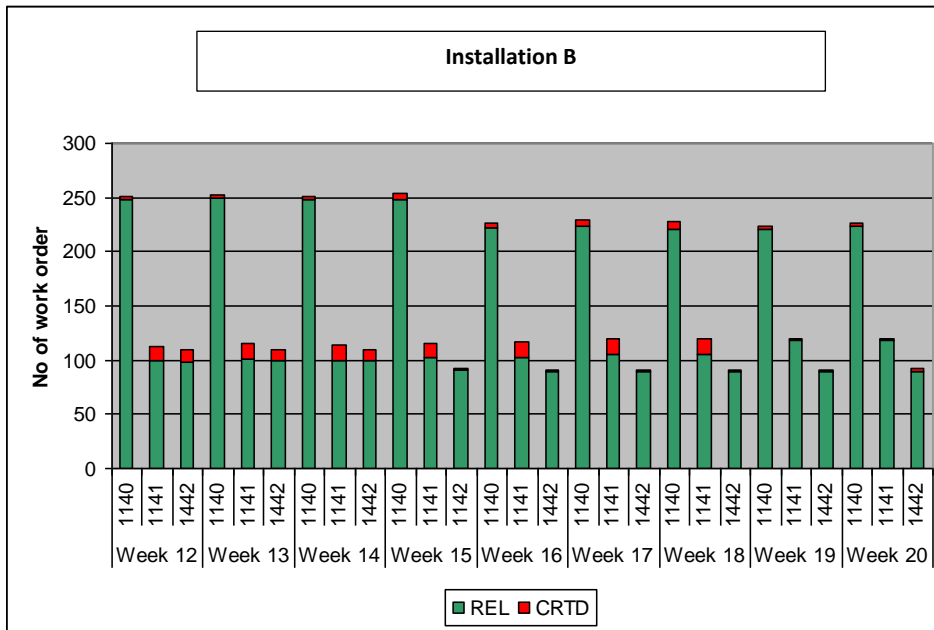
Figur 47 V3 - B (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
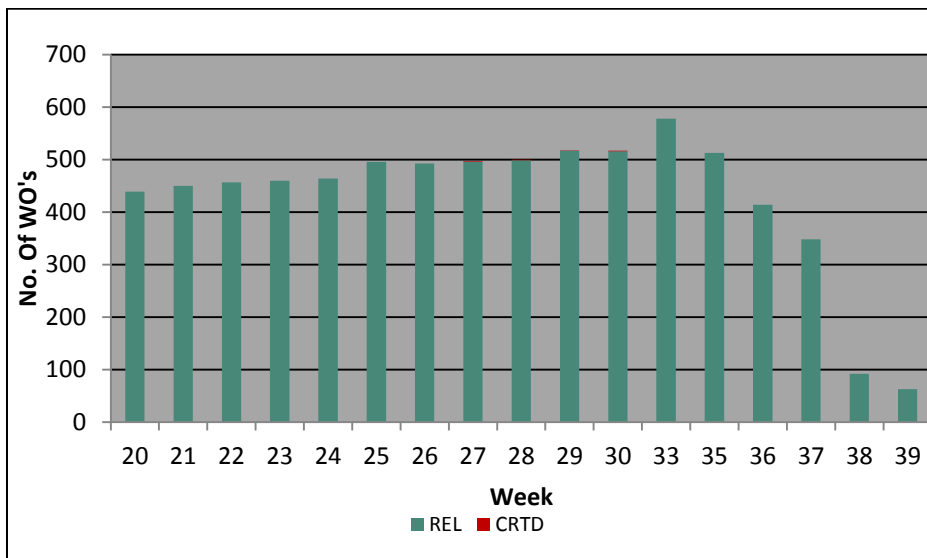
Figur 48 V3 - B

For installation B there are some WO's in CRTD for the first measurement period, but as they are close to eliminated by the end of the first period and the second, the shutdown preparedness has been improved here as well.

4.15   V4 – Old work orders, installation A

Installation A
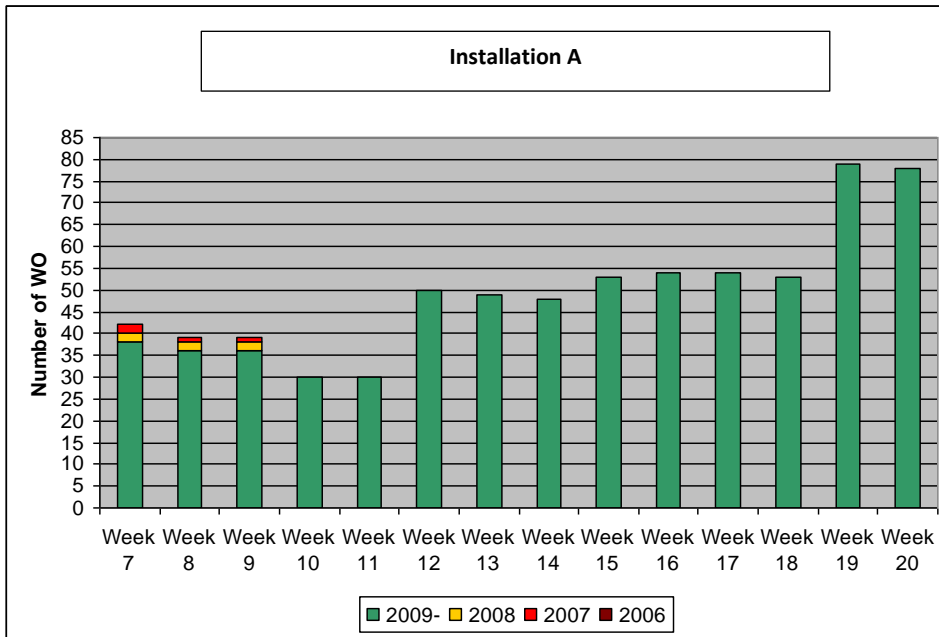
Figur 49 V4 - A (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
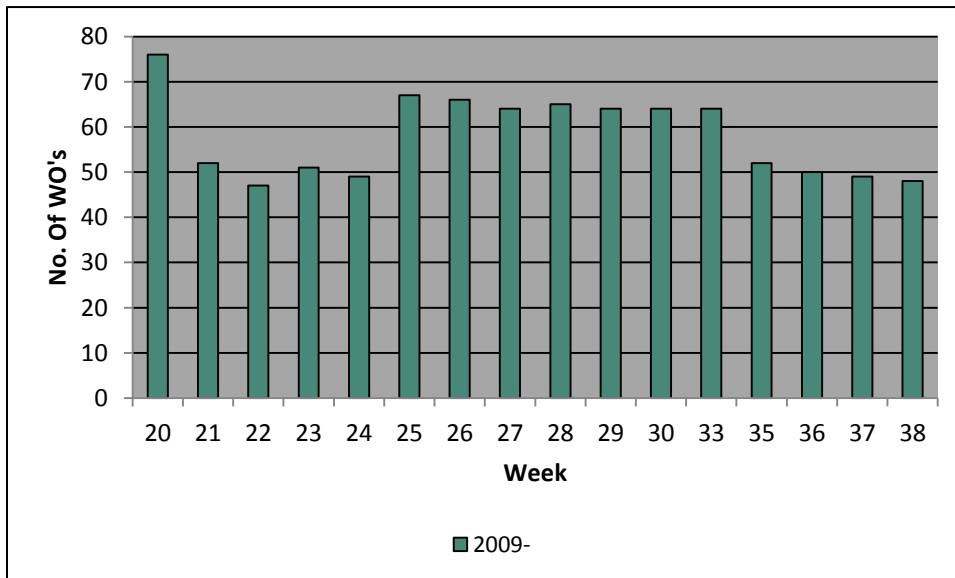
Figur 50 V4 – A

Indicator V4 was created in order to ensure that the information in SAP is up-to-date. As seen from the figures there are no old work orders except for the few in week 7-9 (which are terminated). This tells us that there are no old work orders in SAP for installation A.

V4 – Old work orders, installation B
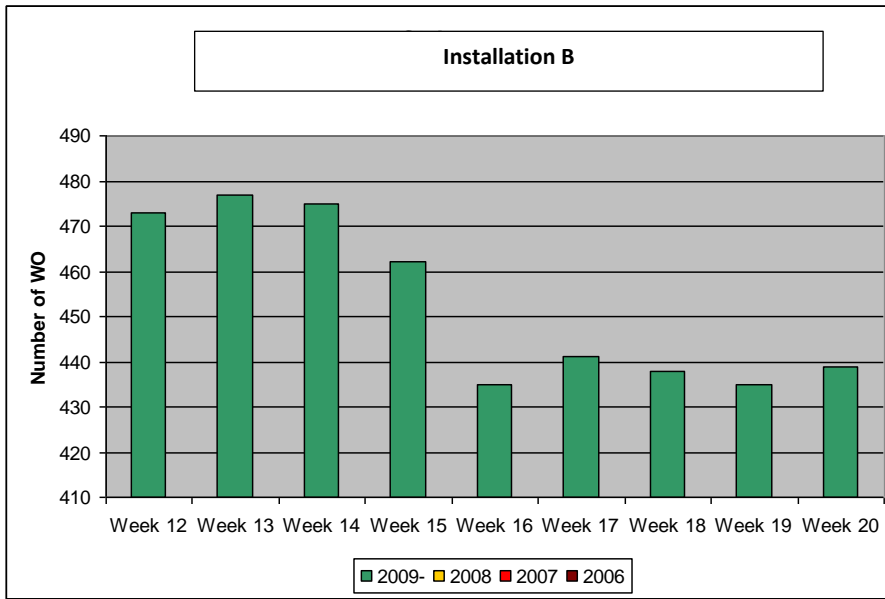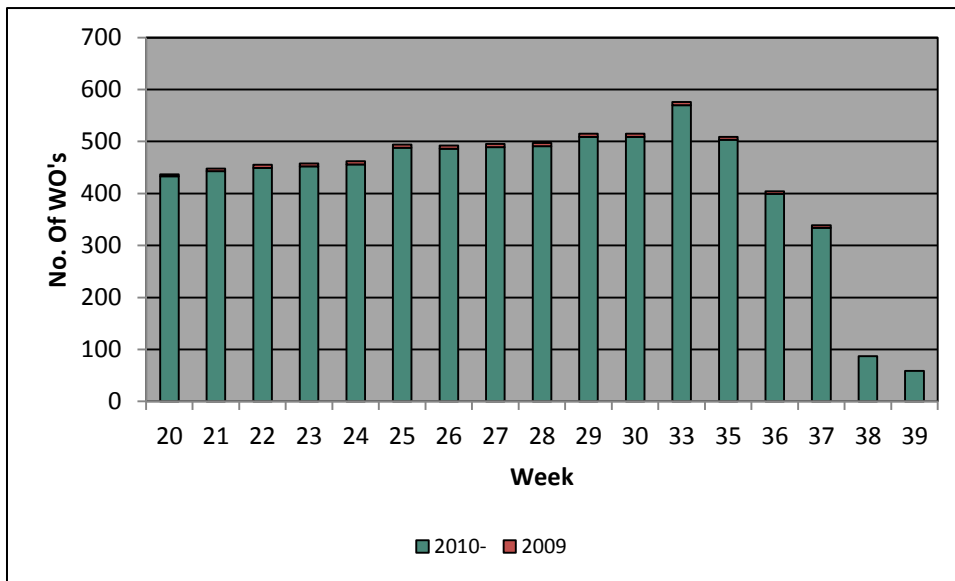
Figur 52 V4 – B

Installation 2 hasn't got any old workers either. The Shutdown Preparedness Report has questioned the usefulness of this indicator, as old work orders obviously isn't a relevant problem.

4.16 V5 – Old work orders, installation A
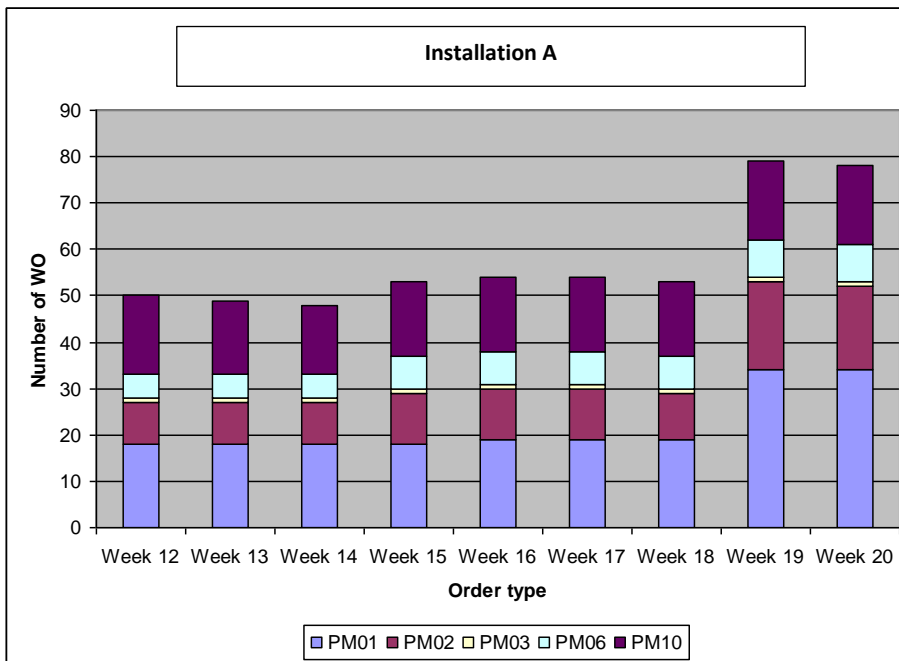
Figur 53 V5 – A (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)
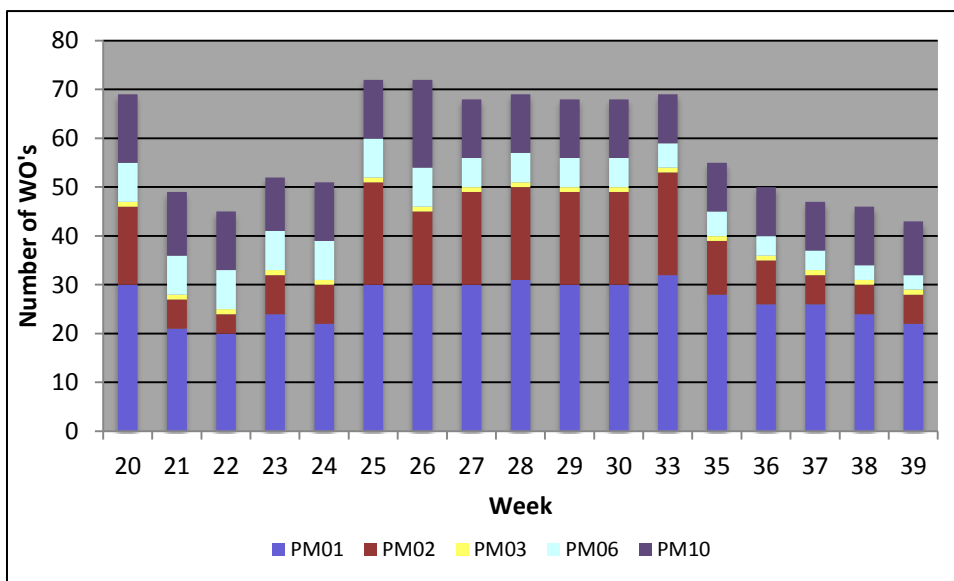
Figur 54 V5 – A

The work orders are registered with order types, which represent preventive maintenance, corrective maintenance, modifications etc. This indicator gives an overview of the volume and type of maintenance work in the system, providing additional information to the indicators V1 and V2 on the work portfolio for execution during an unforeseen shutdown. (Thuestad L. , Utne, Kleppa, Sjøflot, Thorstensen, & Finbak, 2010)

The order types are presented in Chapter 4.3. For the first period everything remains unchanged before PM01 and PM02 increases in week 19-20. They then decrease until week 24, which shows than maintenance work has been done. From week 25-33 the situation is again stable before shutdown work is done and the number of WO's is decreasing for all order types.

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4.17 V5 – Old work orders, installation B
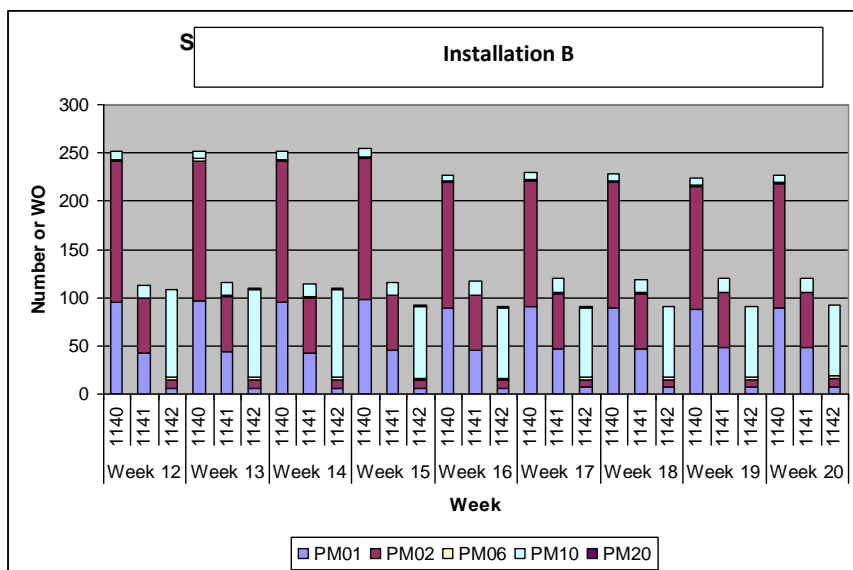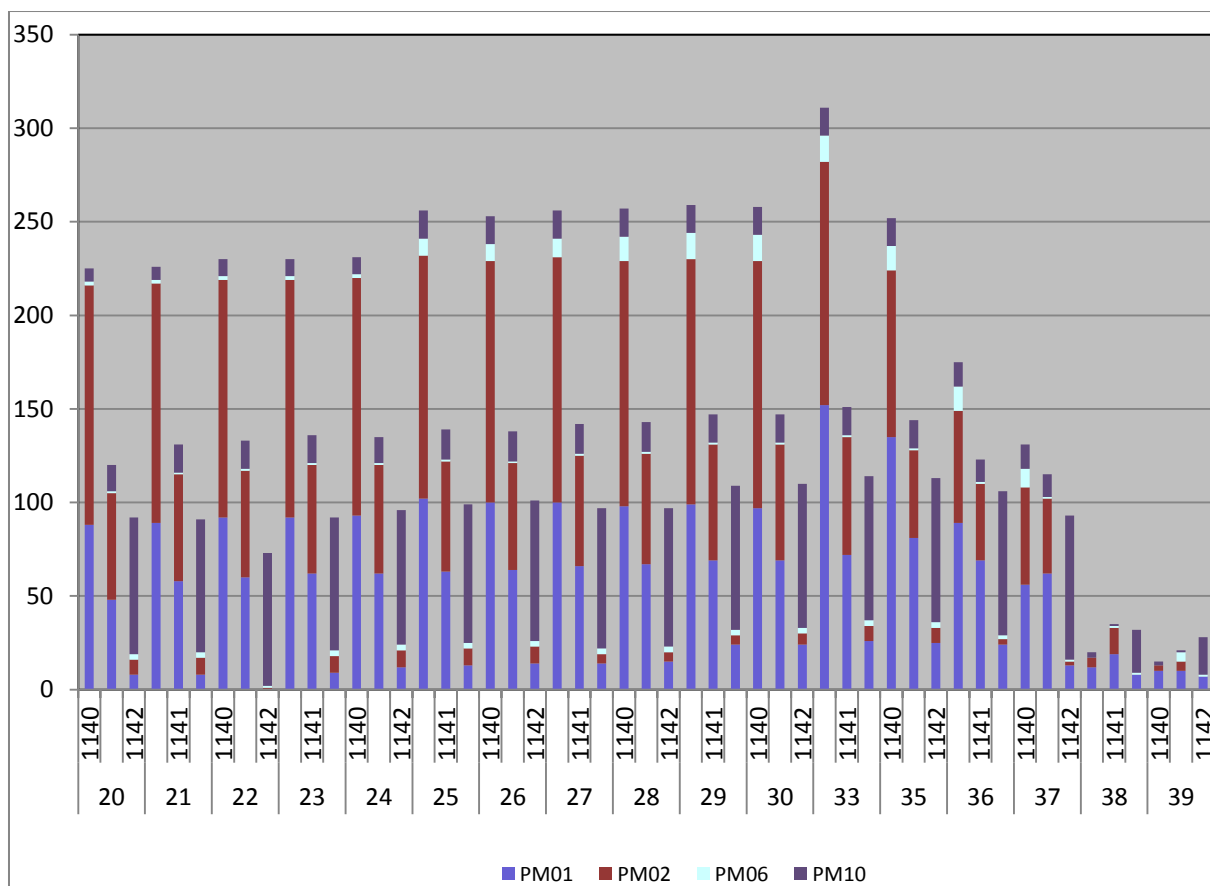
Figur 56 V5 - B

From graph 55 and 56 unit "1142" stands out again. Where "1140" and "1141" has their majority of WO's in PM01 and PM02, "1142" has a predominance of project work orders, PM10. Installation B represents a real case installation, with three units. Given the different nature between the units, the results are not in surprising. Except from this, the numbers of WO's are stable for all the order types, before they all decrease by week 35 (shutdown).

5 Conclusion and further work

It is said that an excellent set of measures does not guarantee a winning strategy, but it certainly increases the chances for success. After every indicator measurement, a conclusion so to speak is given. It's seen that both installation A and B has had shutdown related work in the measured time period. Increase in WO's, followed by a noticeably decrease is a proof of that.

It can be concluded with that the measurements show two stable installations. Where there are prominent changes, it usually is for the better, i.e. improving the shutdown preparedness for the plants. One should however be careful in comparing the two installations too directly, as the indicators are built upon some different fundamentals. Also, they are two different physical assets.

The Quality indicators measures the quality of the work orders from SAP, as the Volume indicators measures the amount of maintenance work in "pipeline" and to what extent this work is ready for execution. As concluded in the A3 – Shutdown Preparedness report, the indicators indicate god possibilities for performing opportunistic maintenance, but that in the case of actually improving shutdown preparedness, more inspection is necessary.

In the corporates perspective all these indicators can be categorized as Performance Indicators. The further work in is then to create a higher level indicator, a Key Performance Indicator, showing how prepared the two installations are to perform opportunistically maintenance in an unforeseen shutdown. This higher level indicator should satisfy the criterion's mentioned in the report, making it more understandable and thus valuable in the corporates perspective. Unfortunately the time scope didn't allowed that for this thesis, but would be very interesting and absolutely feasible.

Learning MS Access is time consuming, but valuable. The group performing shutdown preparedness monitoring at Statoil are using the program, and according to Rasmus Bjerkan, Group Manager at AGR Field Operation, Trondheim, MS Access is an vital tool at their office performing maintenance management. Being so time consuming as it is, it is questionable whether or not this is a good method for Statoil.

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Appendix: Week dump examples

Work order

Order	Week	Description	Order Type	Functional lo	Bas. start date	Basic fin. date	System	Locatic	Revision	System status	User statu:	Main WorkCt	WSC	WSC status	System Highe
20728011	08	Pumpen slår seg ut iblant	PM01	1230-PE-65-	09.12.2005	08.01.2006	65	G24	DISCOS	REL PCNF MANC I	PREP	PPMAUT			0,00
20732362	08	RMS Nye tastaturer til ballast/pos. PCèr	PM01	1230-52	29.01.2007		52	X00	RMS	REL PCNF PRT G	RDEX DUII	PPMAUT			0,00
20755375	08	Bytte feilgravert tekst på matrisen	PM03	1230-IM-79-0	28.03.2006	28.03.2006	79	L10	VGP REST	REL PCNF PRT M	RDEX WP	PPMAUT			0,00
20755424	08	Fjerne Drainsentrifuge fra bilde/logikk/	PM03	1230-XX-56-0	29.01.2007	23.02.2008	56	P10	DISCOS	REL PCNF MANC I	PREP WP	PPMAUT			0,00
20760316	08	Modifisere ventil fra DPE til SPE# SP	PM01	1230-HZV -1;	10.12.2009	16.12.2009	13	P30	TESTSEP	REL PCNF PRT G	RDEX WP	PPMMEC	30	Not shutdow	0,00
20760319	08	Modifisere ventil fra DPE til SPE# SP	PM01	1230-WB-13-	19.11.2009	16.12.2009	13	P30	TESTSEP	REL PRT GMPS	PRCO PL/	PPMMEC	30	Not shutdow	0,00
20784008	08	Oppdatering av Lastkalkulator Tankvolum	PM01	1230-IW-52-0	11.05.2007	16.05.2007	52	L10	RMS	REL PCNF PRT G	RDEX WP	PPMAUT			0,00
20789009	08	Maling/overflatebehandling utvendig	PM01	1230-VA-20-	02.07.2007	01.09.2007	20	P30	MALING	REL CNF PRT M/	PREP	PPMSUR			0,00
20827921	08	Installere alarmlogger for RMS systemet	PM03	1230-IO-05-0	11.05.2007	16.05.2007	05	L10	RMS	REL PCNF GMPS	PREP WP	PPMAUT			0,00
20850734	08	Sløyfetest, strømningsrør I-7 brønn A24	PM10	1230-UC-18-	01.06.2010	31.07.2010	18	U00	AOP10-3	CRTD MANC NMAT	PREP	C01SFVIS			0,00
20851608	08	SAS-SIEMENS: OPPKOBL. AV A25 XMAS	PM10	1230-EV -13	01.06.2010	31.07.2010	13	R10	AOP10-3	REL PCNF PRT G	RDEX	C01SVVIS			0,00
20854159	08	SAS-SIEMENS: NY DIACS IFM BRØNN A2	PM10	1230-EV -13	01.06.2010	31.07.2010	13	R10	AOP10-3	REL PRT GMPS M	PREP	C01SVVIS			0,00
20855245	08	RMS tidsynkroniseres mot GPS klokke	PM03	1230-IO-52-0	11.05.2007	16.05.2007	52	L10	RMS	REL PCNF GMPS	RDEX WP	PPMAUT			0,00
20855317	08	Skjærunit og injeksjonspumpe for slam/s	PM03	1230-00	20.01.2010	26.02.2010	00	D10	VISBS10	REL PCNF GMPS	RDOP WP	BOR	40	Shutdown W	0,00
20861939	08	Optimalisering Nivåstyring for væsketoge	PM03	1230-20	05.02.2007	06.02.2007	20	X00	DISCOS	REL PCNF PRT M	PREP WP	PPMAUT			0,00
20862109	08	NW 929158.Gjenstående punch etter C.C.C	PM10	1230	01.06.2010	31.07.2010		C00	AOP10-3	REL PCNF GMPS	PREP	C01S-HP			0,00
20869662	08	WW: Målingen virker ikke.	PM01	1230-PIT -23	10.12.2006	12.12.2006	23	P30	WOODWARD	REL PCNF PRT G	STRT DUI	PPMAUT			0,00
20872216	08	WW:Feil på overføring av VSV gr.til skje	PM01	1230-GT -80	01.01.2007	15.06.2007	80	C30	WOODWARD	REL PCNF PRT M	PREP WP	PPMAUT			0,00
20872277	08	Fjerning av overflødig utstyr	PM01	1230-WB-23-	01.06.2011	19.06.2011	23	P30	VISRS11	REL PRT CSER M	PREP NTV	C01SLVIS	20	Insufficient W	0,00
20872707	08	Utvendig nærvisuell inspeksjon	PM02	1230-VA-20-	02.05.2011	20.05.2011	20	P30	VISRS11	REL PRT MANC N	RDEX	PPMISP			0,00

Operation

Order	Oper..	Week	Work cent	Opr. short text	Order T	Functional	Locatic	Sy	Ho	Work	Actual v	Sto	Contro	Latest start	Lat.finish dat	Actual start	Act.finish da	System	Status
20728011	0010	08	PPMAUT	Pumpen slår seg ut iblant	PM01	1230-PE-6	G24		1,0	0,000			PM01	29.02.2008	29.02.2008			REL	
20728011	0020	08	L-AUT	Assistanse ved feilsøking	PM01	1230-PE-6	G24		0,0	5,000			PM01	01.03.2008	01.03.2008	05.07.2007	05.07.2007	PCNF REL	
20732362	0110	08	L-AUT	Dokumentasjonsoppdatering	PM01	1230-52	X00		11,0	0,000			PM01	06.09.2009	07.09.2009			REL	
20755375	0050	08	PPMAUT	HS-79	PM03	1230-IM-79	L10		1,0	0,000			PM01	19.02.2010	19.02.2010			REL	
20755375	0070	08	PPMAUT	EV -45-0602	PM03	1230-IM-79	L10		1,0	0,000			PM01	19.02.2010	19.02.2010			REL	
20755375	0080	08	PPMAUT	EV -45-0126	PM03	1230-IM-79	L10		1,0	0,000			PM01	19.02.2010	19.02.2010			REL	
20755375	0090	08	PPMAUT	NRA -70-0106	PM03	1230-IM-79	L10		1,0	0,000			PM01	19.02.2010	19.02.2010			REL	
20755375	0100	08	PPMAUT	NRA -70-0246	PM03	1230-IM-79	L10		1,0	0,000			PM01	19.02.2010	20.02.2010			REL	
20755375	0110	08	PPMAUT	NTA -79-0304	PM03	1230-IM-79	L10		1,0	0,000			PM01	20.02.2010	20.02.2010			REL	
20755375	0120	08	PPMAUT	HS -72-3015PAA	PM03	1230-IM-79	L10		1,0	0,000			PM01	20.02.2010	20.02.2010			REL	
20755424	0020	08	PPMAUT	Fjerne Drainsentrifuge fra logikk	PM03	1230-XX-56	P10		50,0	0,000			PM01	19.02.2010	27.02.2010			REL	
20755424	0030	08	PPMAUT	Fjerne Drainsentrifuge fra FTC	PM03	1230-XX-56	P10		0,0	0,000			PM01	27.02.2010	27.02.2010			REL	
20760316	0010	08	PPMMEC	Modifisere ventil fra DPE til SPE	PM01	1230-HZV	P30		20,0	0,000			PM01	11.12.2009	12.12.2009			REL	
20760316	0007	08	PPMAUT	Frakoble for mekanisk ventil	PM01	1230-HZV	P30		2,0	0,000			PM01	10.12.2009	11.12.2009			REL	
20760316	0030	08	PPMAUT	Tilkoble ventil/testkjøre	PM01	1230-HZV	P30		2,0	0,000			PM01	12.12.2009	13.12.2009			REL	
20760316	0005	08	POMPRO	Klargjøring av drift	PM01	1230-HZV	P30		10,0	12,000			PM01	10.12.2009	10.12.2009	14.04.2008	15.04.2008	PCNF REL	
20760316	0031	08	POMPRO	Tilbakestilling av drift	PM01	1230-HZV	P30		1,0	0,000			PM01	13.12.2009	13.12.2009			REL	
20760319	0010	08	PPMMEC	Modifisere ventil fra DPE til SPE	PM01	1230-WB-	P30		18,0	0,000			PM01	19.11.2009	20.11.2009			REL	
20760319	0005	08	POMPRO	Klargjøring	PM01	1230-WB-	P30		1,0	0,000			PM01	19.11.2009	19.11.2009			REL	
20760319	0020	08	POMPRO	Tilbakestilling av drift	PM01	1230-WB-	P30		1,0	0,000			PM01	20.11.2009	20.11.2009			REL	

Material

Order	We	Short text	Pri	Offshore	Hc	Plant	User status	S	Functional L	Start	Mat. ETA
20732362	08	RMS Nye tastaturer til ballast/pos. PCèr	L	@0A@		1230	RDEX DUIN WP		1230-52	29.01.2007	17.01.2008
21326740	08	Oppmåling/ inst. av nye isol.kasser, DBB	L	@0A@		1230	PREP		1230-WB-23-	15.02.2007	15.02.2007
20784008	08	Oppdatering av Lastkalkulator Tankvolum	U	@08@		1230	RDEX WP		1230-IW-52-(	11.05.2007	23.03.2007
20827921	08	Installere alarmlogger for RMS systemet	M	@08@		1230	PREP WP		1230-IO-05-0	11.05.2007	24.03.2007
20855245	08	RMS tidsynkroniseres mot GPS klokke	L	@08@		1230	RDEX WP SJA		1230-IO-52-0	11.05.2007	03.02.2009
20886884	08	Hot Standby datamaskin til ankervinsjsys	L	@08@		1230	PREP		1230-IO-05-0	11.05.2007	21.05.2007
20902423	08	Opprydding i RMS kabinett	L	@08@		1230	STRT WP		1230-05	11.06.2007	12.09.2008
20945179	08	Trekke fiberkabel C2112 -L3152	M	@0A@		1230	STRT WP		1230-IC-80-0	01.07.2007	29.01.2009
20945181	08	IO: Oppkobling av Prograf på S@P	L	@08@		1230	STRT DUIN WP		1230-69	01.07.2007	26.10.2009
20946264	08	Oppgradering fra step 5 til step 7.	U	@08@		1230	RDEX WP		1230-69	03.08.2007	06.09.2007
21213829	08	Best. av bolter m/mutter til nye carrier	L	@0A@	X	1230	PREP SHUT FR			24.08.2007	18.09.2009
20978177	08	BN System 1 ligger i ubeskyttet nett*	M	@0A@		1230	STRT WP		1230-68	01.10.2007	11.12.2009
20873139	08	Installere ny monorail for 23-HZV-0177	L	@08@		1230	PREP WP SJA		1230-HZV -2:	01.03.2008	26.07.2007
20964639	08	IO: Oppgarder HMI og koble mot S@P	L	@08@		1230	STRT PLAN WF		1230-IO-80-0	02.04.2008	04.03.2009
20994485	08	Bytte gyro	L	@0A@		1230	STRT WP		1230-JE-93-(	21.04.2008	06.02.2009
21035075	08	Skifte Bundle 6 tr Kompressor	U	@08@		1230	RDOP NTWR W		1230-KA-23-:	28.05.2008	28.05.2008
21034609	08	Bestilling av utstyr og personell fra BJ	U	@0A@		1230	PREP SHUT WI		1230-P30	01.06.2008	27.05.2008
21140806	08	Mye rust på solenoider og spalter.	U	@08@		1230	RDEX		1230-IV-45-0	14.11.2008	14.11.2008
21203888	08	Insp av guideskinne for tennerør.	L	@08@		1230	RDEX SHUT FR		1230-43-RØF	25.05.2009	25.05.2009
20873784	08	BESTILLING AV DBB VENTILER		@09@	X	1230	PREP NTWR W		1230-P30	29.05.2009	31.10.2008

Work permit

Status	Work Permit	We	Locat	Work description1	Hc	H(	Ent	Iss	PT	Wa	DS	Rm	W(	Ex	Cl(	Ot	Wh	From hr.	To hr.	Extended	Applicant name
@06@	9502360987	08	C10	Skjærpumpe Mek.														00:10:00	23:55:00	00:00:00	Jarle Haugstad
@06@	9502342434	08	D10	Skjærpumpe Mek.														00:10:00	23:55:00	00:00:00	Knut Normann H(
@07@	9502357574	08	D10	Skjærpumpe Mek.														00:10:00	23:55:00	00:00:00	Jarle Haugstad
@07@	9502327829	08	D10	Fjerning av kabler/MCC s														00:10:00	23:55:00	00:00:00	Mads Monstad/E
@07@	9502327746	08	D10	Installasjon nytt utstyr – /														00:10:00	23:55:00	00:00:00	Knut Normann H(
@07@	9502330443	08	D10	Fjerning og trekking av ka														00:10:00	23:55:00	00:00:00	Knut Normann H(
@07@	9502351767	08	D10	MudMix Mek&rør														00:10:00	23:55:00	00:00:00	Mads Monstad
@07@	9502351768	08	D10	Mudmix E&I: montering a														00:10:00	23:55:00	00:00:00	Mads Monstad
@07@	9502335385	08	D10	MudMix E&I: Arbeid i LIR														00:10:00	23:55:00	00:00:00	Even Moldsvor/Kı
@07@	9502335404	08	D10	MudMix E&I: Kabeltrekkiı														00:10:00	23:55:00	00:00:00	Even Moldsvor/Kı
@07@	9502342027	08	D10	MudMix E&I: Arbeid i LIR														00:10:00	23:55:00	00:00:00	Mads Monstad
@07@	9502326919	08	D20	Bygge stillas i mikserom														00:10:00	23:55:00	00:00:00	Geir Vilhelmsen
@07@	9502357664	08	D30	Tubing fra plant air på boı														00:10:00	23:55:00	00:00:00	Torfinn Heier
@07@	9502360141	08	D30	Montering av braketter og														00:10:00	23:55:00	00:00:00	Torfinn Heier
@07@	9502243556	08	D30	Installasjon av HVAC anle														00:10:00	23:55:00	00:00:00	Jarle Haugstad
@07@	9502337634	08	D30	HANDLING AV SUBSEA														00:10:00	23:55:00	00:00:00	Per-Ole Ingebrigts
@07@	9502232438	08	L10	Riving av Gammel Gyro														00:10:00	23:55:00	00:00:00	Per Einar Lorents
@07@	9502239249	08	L10	Montering av utstyr i IC-6!														00:10:00	23:55:00	00:00:00	Per Einar Lorents
@07@	9502343175	08	L20	HW-Connection change 3						X								07:00:00	19:00:00	00:00:00	Per Einar Lorents
@07@	9502344522	08	L30	Varmtarbeid i sveiseverks														00:10:00	23:55:00	00:00:00	Gunnar Veivåg

Work Orde	Tag/line nc	Discipline	Approver -	HSE Fu	Senior ap	Leve	SJA	Text	S	From Date	To Date
20855317	1230-00	BOR	Eirik Skars			2			@0Z@	19.02.2010	23.02.2010
20855317	1230-00	BOR	Reidar L. F			2			@0Z@	10.02.2010	23.02.2010
20855317	1230-00	BOR	Eirik Skars			2			@0Z@	18.02.2010	23.02.2010
21241852	1230-XX-11	BOR	Johnny Gje			2			@0Z@	03.02.2010	09.02.2010
21241852	1230-XX-11	BOR	Johnny Gje			2	X		@0Z@	03.02.2010	09.02.2010
21241852	1230-XX-11	BOR	Frode Rydı			2			@0Z@	03.02.2010	10.02.2010
21241852	1230-XX-11	BOR	Reidar L. F			2			@0Z@	15.02.2010	23.02.2010
21241852	1230-XX-11	BOR	Reidar L. F			2			@0Z@	15.02.2010	23.02.2010
21241852	1230-XX-11	BOR	Ingvald Gra			2			@0Z@	07.02.2010	09.02.2010
21241852	1230-XX-11	BOR	Ingvald Gra			2			@0Z@	07.02.2010	09.02.2010
21241852	1230-XX-11	BOR	Reidar L. F			2			@0Z@	10.02.2010	23.02.2010
21241852	1230-XX-11	C01SSVIS	Johnny Gje			2			@0Z@	02.02.2010	09.02.2010
21128339	1230-AF-0:	BOR	Eirik Skars			2			@0Z@	17.02.2010	23.02.2010
21128339	1230-AF-0:	BOR	Eirik Skars			2			@0Z@	19.02.2010	23.02.2010
21322863	1230-CF-1	BOR	Eirik Skars			2	X		@0Z@	14.02.2010	23.02.2010
21295590		POMPRO	Ingvald Gra			2			@0Z@	08.02.2010	15.02.2010
20994485	1230-JE-9:	IMOTEL	Terje Nikø			2			@0Z@	10.12.2009	14.12.2009
20978177	1230-68	PPMAUT	Heine Skei			2			@0Z@	14.12.2009	16.12.2009
21469691	1230-UR-1	PPMAUT	Harald Edv	Jan Erik	Ottar Sk(	1	X		@0Z@	11.02.2010	11.02.2010
21266125		C01SLVIS	Bjørn Ohm			2			@0Z@	12.02.2010	16.02.2010