University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: OFFSHORE TECHNOLOGY/ INDUSTRIAL ASSET MANAGEMENT	Spring semester, 2017...... Restricted access
Writer: Mohamed Anwar Abdel Samia Khodair	Mohamed Anwar

Faculty supervisor: Professor Knut Erik Bang

External supervisor(s): Mr. Jan Inge Vaage

Title of thesis:

Implementation of TPM on Roxar's three-phase closed flow loop.

Credits (ECTS): 30

Key words: **TPM , OEE , big losses, PM, flow loop, Implementation plan, Criticality analysis, Spare parts management, Life cycle cost, Agile PM,**	Pages: 80 Stavanger, June 2017.

TABLE OF CONTENTS

TABLE OF FIGURES

ABBREVIATIONS

APM	Agile models Project Management
eAM	Enterprise Asset Managment – Orcale Module
KPI	Key Performance Indicator
MPFM	Mulit Phase Flow Meter
MPX	Emertxe Project Management
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
PM	Project Management
PMLC	Project Management Life Cycle
TPM	Total Productive Maintenance
TPM	Traditional Project Management
XPM	Extreme models Project Management

DEDICATION

I dedicate this thesis to the souls of my dad Mr. Anwar Khodair, my friends Mahmoud El-Touny, Mohamed Sabek and Maged Mohamed and to rest of my family mom, wife, siblings and kids.

Thanks to all you for being the driven force behind my determination and persistence to accomplish this task.

Best Regards,

Mohamed Anwar

Mohamed Anwar Abdel-Samia Khodair.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to:

My thesis supervisor at the University of Stavanger Prof. Knut Erik Bang for his valuable support and guidance throughout the thesis.

My thesis supervisor at Emerson/ Roxar Flow Measurements As, Mr. Jan Inge Vaage for his valuable time, knowledge and ideas.

Mr. Eivind Ekrene Manufacture engineer, Mr. Helge Bjorland Team Manager Production & Calibration and Mr. Eirik Eskeland Senior Technician for giving me the time from their busy schedule and for their valuable advices throughout the thesis.

ABSTRACT

This thesis demonstrates how to implement the TPM programme on Roxar's flow loop. Roxar is a flow measurement technology company and it is a part of Emerson companies' portfolio. Roxar's manufacturing factory is located in Stavanger Norway and it includes the flow loop. The flow loop consists of test separator, reference system, control system and compressor units and nitrogen generator. Emerson management identified this flow loop as one on Emerson's critical assets. Therefore; Emerson management decided to include it into the TPM implementation programme.

Emerson/Roxar kicked-off the TPM programme prior to the start of the thesis. Therefore, it was important to evaluate where Emerson/Roxar is in the TPM implementation process in order to determine how this thesis can add value. The evaluation indicated that Emerson/Roxar is in an early stage of the TPM programme implementation.

The objectives of this thesis were set based on the outcome of above mentioned evaluation. These objectives are the following: develop OEE system; develop equipment criticality analyses; develop methodology to calculate the life cycle cost of new equipment; suggest an implementation plan. Throughout the thesis some systems were developed to calculate the OEE and to rank the equipment with respect to its criticality. Furthermore, the implementation plan and the life cycle calculation methods were developed. The developed systems revealed interesting results, such as the flow loop big losses and mapping the critical and serious equipment per each main function of the flow loop. That said the OEE system is the most interesting result because it is a key tool to identify the potential improvement opportunities.

At the end of this thesis, recommendations were made in order to enhance the systems which were developed during the thesis ; enhance the quality process of the data gathering; create a cross-functional team in order to drive the TPM implementation in a rapid manner through the Emerson/ Roxar organization; and finally to improve the operators' competencies and skills.

1 Introduction

1.1 Background

TPM originated from Japan as an equipment management strategy designed to support the total quality management strategy. TPM is a world-class approach to equipment management that involves many people in the organizations in order to increase the equipment effectiveness. The TPM key objective is to continuously enhance the availability and prevent the degradation of equipment through the continuous developing of existing maintenance systems.

1.2 Company presentation

According to the Emerson's official web-site, Emerson consists of five business segments which are Network Power, Process Management, Industrial Automation, Climate Technologies, and Tools and Storage. Roxar is a flow measurement technology company and it is part of Emerson process management business segment.

Emerson has many factories all over the world. Therefore, Emerson management aims to ensure that customers consistently receive same high-quality products on time; perfect execution is followed in all factories worldwide; regionalize the global production of the same products in different world areas. Emerson management kicked off a strategic initiative called one factory in order to achieve mentioned goals. The one factory strategic initiative consists of 6 main pillars which are (1) Safety Culture is the number one value, (2) Total Productive Maintenance using eAM (3) Process Compliance Audits (4) Key Process Expert Matrix, (5) Performance Metrics and (6) Governance Structure.

1.3 Objective

The objective of this thesis is to assist Emerson /Roxar in implementing the TPM programme on the flow loop equipment. Achieving this objective requires the following: develop a system to capture and visualise the overall equipment effectiveness (OEE) and the big losses in order to identify the improvement opportunities based on factual and scientific approach; develop equipment criticality analyses in order to rank the flow loop equipment with respect to their impacts on the availability, performance and quality of the flow loop; develop a methodology to calculate the life cycle cost of new equipment.; and finally develop an overall implementation plans which illustrates how to build high-level implementation plan, factors influencing implementation and suggested project management model.

1.4 Method

This thesis started with a basic research and study whereby I read through many thesis with similar or closely related subjects and other sources. The second step was the objectives identification that is why many meetings were held with external supervisor Mr. Jan Inge in order to set clear objectives and deliverables for this thesis. The third step was conducting a site survey on the flow loop in order to be conscious of the loop equipment, structure, and operation. The fourth step was to break down identified objectives into tangible and achievable sub-objectives. These sub-objectives are the following: developed a system that captures and visualizes the OEE and seven big losses; create quantitative analysis to rank the flow loop equipment with respects to their in on the loop functionality; develop a method to calculate the life cycle cost of equipment and implementation plan. The fifth step was gathering and discussing the data with Professor Knut and Mr. Inge. Finally, make a set of recommendations and the conclusion.

1.5 Delimitations

The duration of this master thesis was around 18 weeks and some of these were spent on the theoretical research of the topic; developing OEE and big losses system; developing equipment criticality quantitative analyses; developing life cycle cost calculation. Consequently, only collected four weeks data. The four weeks is very short period and insufficient to afford conclusive observation. That said, the four weeks data revealed an interesting observation about installation and uninstallation time, Therefore, it is recommended to continue utilizing the OEE in order to determine potential improvement opportunities.

There are three parameters which enable companies to select the most cost efficient maintenance system. These parameters are equipment criticality; equipment probability failure and cost of possible maintenance systems. In this thesis, I managed only to develop the equipment criticality via quantitative analyses. If time allowed me, I would have contacted the equipment suppliers in order to identify failure probability and recommended maintenance systems and it is associated cost.

2 Roxar profile

2.1 Background

Roxar is part of Emerson process management business segment. Most of Roxar products used in the upstream oil and gas industry and particularly in the reservoir management. The products portfolio of Roxar can be found on this link http://www.emerson.com/en-us/automation/roxar.

Topside MPFM

Subsea MPFM

Subsea WGM

WCM

Figure 1 Part of Roxar Products portfolio

One of the main products for Roxar is the multiphase flow meter. The multiphase flow meter used in the upstream oil and gas industry. This meter measures the oil, gas and water flow rates without physical separation. Roxar produces subsea and surfaces multiphase flow meters. These products are shown in Figure1. The manufacturing process of the multiphase flow meter product is a complex process. Initially, MPFM size determined based on the expected operating conditions , then the necessary material, and parts procured, then mechanical and electronic assembly, then dry testing, static calibration of the various sensors. The last stage in the manufacturing process is the dynamic verification of the performance MPFM.

2.2 Flow loop description.

According to the Roxar internal document number 3182641-PAS-FS-F1, the main purpose of the flow loop is to test Roxar multiphase meters in order to verify that they are operating according to their specifications in dynamic conditions. The flow parameters tested are total liquid volume flow rate, gas volume flow rate and the water cut. The water cut is ration between the water rate over the total liquid rate.

The Roxar flow loop facility is a closed multiphase loop with single phase measurements. Single phase measurements mean that the oil, water and gas phases are being measured separately in the reference meter sections using coriolis meters prior to being mixed and sent through the test section.

The flow loop has 3” and 6” sections for measuring single liquid phases, the single gas phase is measured in either a ¼” or a ½” section. Pressure and temperature transmitters used for reference readings are installed in the test section.

The test section has two 3” and one 6” test sections where multiphase meters can be installed, remote operated valves enables switching between the two 3” test sections making testing of two multiphase meters in parallel possible. In all test sections the multiphase flow is passed through a blind-T upstream of the multiphase meter being tested.

Downstream of the test sections, the multiphase fluid flow is separated into single phases in a gravity separator. The separator tank usually contains approx. 10m3 of each fluid phase.

Gas flow rate is calculated by using the mass flow measurement from the gas coriolis and the pressure and temperature in the test section.

DeltaV automation system is used for operating the flow loop and logging data from both the reference instrumentation and the multiphase meters.

As safety precaution, three emergency stop buttons is placed in the plant area. By releasing on of these the rig will automatically shut down. All pipe line valves will go to fail safe positions and the pumps will stop. XV-3019 will release the separator pressure to atmosphere. When safe condition to restart the rig is regained the emergency shutdown must be reset from DeltaV™ as well.

In the plant area there are four oxygen meters. If either one of these detects an oxygen level lower than 18,5 % the rig will automatically shut down. All pipe line valves will go to fail safe positions and the pumps will stop. XV-3019 will release the separator pressure to atmosphere. When safe condition to restart, the rig is regained the emergency shutdown must be reset from DeltaV™ as well.

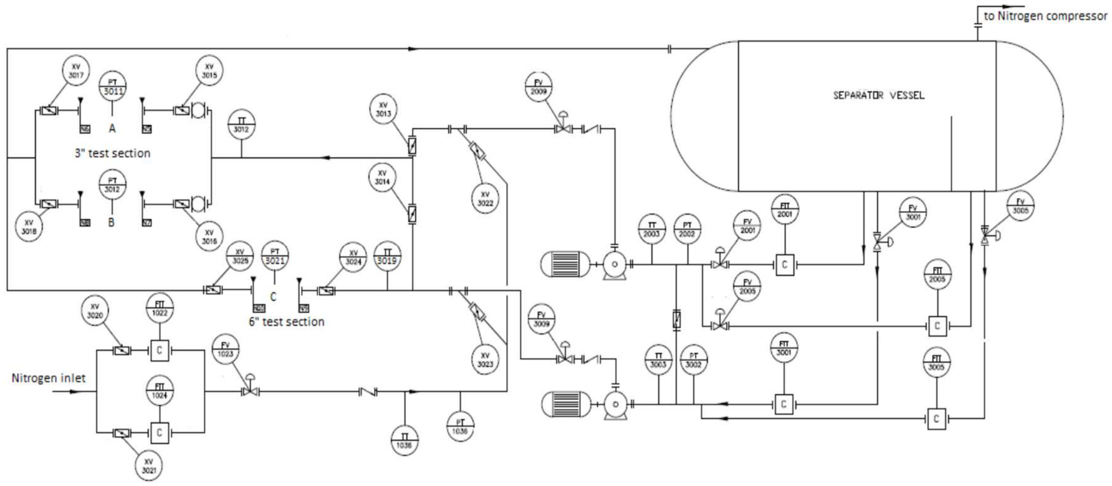


Figure 2: Schematic diagram of the flow loop

Figure 3: Real picture of the flow loop

Figures 4 and 5 provide more details about the flow loop such as the location, flow rates capacity pressure and temperature range, piping material and mechanical interface and fluid properties.

Location: Stavanger, Norway (indoor facility)	Liquid flow range: 2 - 250 m3/h
Test units interface: 3" 150 RF schedule 10	Gas flow range 20 – 260 m3/h
Temperature range: 15 – 35°C (not adjustable)	Piping material: 316
Pressure range: 4 - 10 bara	**Gas:** 95% Nitrogen, 5% air
Water: Salted tap water (NaCl)	Typical density: 1023 kg/m3

Figure 4: Flow loop specifications

Typical salinity: 37 PPT (may be adjusted)	Typical conductivity: 50mS/cm @ 20°C
Oil: Shell Diesel	Typical density: 830 – 850 kg/m3
Typical viscosity: 1.5 – 4.5 cSt / 20°C	Relative permittivity: 2.1 – 2.3

Figure 5: Fluid properties of the flow loop

2.3 Flow loop operation guideline

According to the Vileiniskis et al (2016, 215-230), The three-phase test separator is a conventual measurement system that is used in the oil production platforms. There are many different types of separators, but the most common ones being horizontal due to the ease of maintenance, good separation quality and low initial set-up costs. Roxar has a horizontal separator, this unit is responsible for separating gas, water and oil. The separation is based on the laws of gravity, allowing a liquid with a higher density, such as water, to settle down in the bottom of the separator, while liquid with a lower density, such as oil, as well as gas, to flow on the top of the separator. After the physical separation, each phase is measured separately. It is known that the measurement uncertainty in single phase is a lot higher than the uncertainty in the 3 phase.
According to the Vileiniskis et al (2016, 215-230), A schematic diagram of a typical horizontal three-phase gravity separator with a weir can be seen in **Figure 6.** The whole vessel can be roughly divided into three sections.
1. The gravity settling section (or the liquid separation section), where the separation of water and oil takes place (the section to the left of the weir).
2. The separated oil section, where the separated oil flows from the liquid separation section (the section to the right of the weir).
3. The remaining space of the vessel is left for the gas phase (separated gas section).

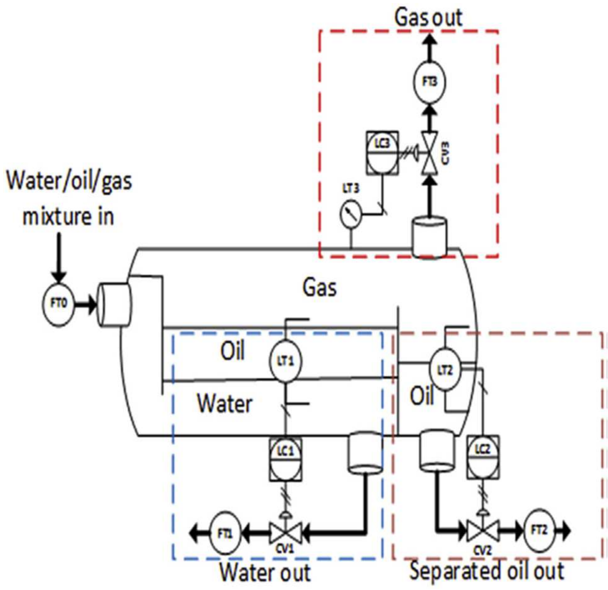


Figure 6: Schematic of diagram three-phase separator Vileiniskis et al (2016, 215-230)

According to the Vileiniskis et al (2016, 215-230), PI controller provides a control command to keep the control valve CV1 at the necessary opening so that the water oil interface is maintained at the desired level. The control valve provides a way to control the water oil interface level in the gravity settling section by opening/closing when the corresponding command is received from the controller LC1

According to the Vileiniskis et al (2016, 215-230), the pressure transmitter: Measures the pressure in the separator. Provides the information to control the pressure inside the vessel for the safe and efficient use of the separator. Gas reference: Measures the flow of the gas allowed by the opening of the control valve CV3 to monitor the outflowing gas from the separator. Liquid reference: Measures the flow of the liquid allowed by the opening of the control valve CV2 to monitor the outflowing separated oil from the separator.

There is N2 generator and the main purpose of the N2 process is to extract N2 from the surrounding air, compress it in receiver tanks and inject it into the main process line just before the multiphase meters installation point. The N2 is fed to the main process from 62-VK103. If a low gas flow is required XV-3020 is opened. The gas flow will then be controlled by a PI control loop utilizing FV-1023 and calculated N2 flow in the test section. If a high gas flow is required XV-3021 is opened. The gas flow will then be controlled by a PI control loop utilizing FV-1023 and calculated N2 flow in the test section. If the process is running in the 3” flow loop N2 is fed into this pipe line through XV-3022. If the process is running in the 6” flow loop N2 is fed into this pipe line through XV-3023.

When the gas passes through the multiphase meter in the test unit, it is re-circulated to 62-VK102 receiver via the separator vessel 62-VK104. No gas is released to the environment during testing. It is not possible to start and stop 62-KA01 compressor unit, 62-CV100 nitrogen generator and 62-PB03 circulation compressor from DeltaV™.

3 TPM theory

This chapter illustrates the literature content of this thesis. The coming subchapters provide a brief description about the development of the maintenance strategy from its initial run to fail approach until the TPM approach; describes what the TPM is, describes the initial and the modernized classification of the TPM main pillars, describes the main objectives of the TPM and finally describes in details some of the key aspects of the TPM such as the 5S, six big losses, and OEE.

3.1 Historical timeline of the maintenance strategies development

The asset maintenance concept or strategy has been developed considerably. The early asset maintenance approach was known as breakdown maintenance or corrective maintenance and, in this early approach, the main target was to bring the equipment back up and running after it had broken down. During that time, the equipment operators' attitude was one of "I only operate the equipment, it's the job of maintenance stuff to fix it". The next generation of the maintenance was the preventive maintenance. In this approach, maintenance was based on the understanding that, if you planned the stopping of equipment and performed regularly scheduled maintenance, then undesirable breakdowns could be reduced or avoided completely. The third generation was perceived maintenance whereby some of the manual and /or automated conditions monitoring techniques were used to report the equipment's performance (Mobley, 2008).
According to Mobley (2008), the next generation of maintenance brings us to TPM (total productive maintenance). TPM is a world-class approach to equipment management that involves everyone, working to increase equipment effectiveness. TPM provides a comprehensive life-cycle approach to equipment management that minimises equipment failures, production defects, and accidents. It involves everyone in the organisation, from top level management to production mechanics and support groups to outside suppliers. Take a car for example, the owner (equipment operator) performs minor maintenance activities, such as checking the oil, checking the air in the tires, perhaps even giving the car a tune up. However, if something major goes wrong, an expert auto mechanic (maintenance technician) is called in to perform the difficult tasks. The important distinction between this car analogy and production equipment is that most traditional organisations treat their equipment as if it were a rental car. TPM is often implemented as a standalone improvement activity. However, it should be done in concert with the other elements of a world-class manufacturing system.

3.2 TPM objectives

According to Mauric Brien (2015), TPM has many objectives, such as: (1) continuously enhancing the availability and preventing the degradation of equipment; (2) developing the existing maintenance systems and restoring equipment to the optimal condition; (3) determining issues as early as possible and implementing repairs; (4) improving the KPI of the Overall Equipment Effectiveness (OEE); (5) conducting training to develop the skills of operations and maintenance personnel; (6) involving everyone and utilising cross-functional teamwork.

Achieving these objectives requires strong management support as well as continuous use of work teams and small group activities. Practically, these objectives can be achieved by eliminating or reducing breakdowns, stops and rejects, maximising the utilisation of the assets and by reducing cycle times by eliminating stops or slow running of the machine.

3.3 TPM initial structure

According to the (Mobley, 2008), The TPM's main structure consists of three main pillars, as described below:

First pillar (autonomous maintenance): The operators are more familiar with their equipment than anybody else and they are the ones who deal with it on an hourly basis, so they can quickly notice any strange performance or behaviour. Consequently, autonomous maintenance utilises the machine operators to carry out part of the routine maintenance tasks, such as the daily cleaning, inspecting, tightening and lubricating that the equipment requires (Mobley, 2008)

Second pillar (planned maintenance): This is a proactive approach to maintenance. Planned maintenance, also known as preventive maintenance, is used to replace components before they break down. This approach requires the production schedule to accommodate planned downtime to perform equipment repairs and allowing these repairs to be treated as a priority. Figure 7 shows the theoretical trade-off between planned and unplanned maintenanc(Mobley, 20008).

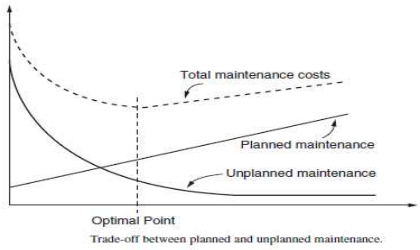


Figure 7: Trade-off between planned and unplanned maintenance (Mobley, 2008)

Third Pillar (maintenance reduction): This pillar is made up of two concepts. The first concept is identifying the equipment specifications during the design and the second concept is predictive maintenance. These two concepts are focused on reducing the overall amount of maintenance that is required, which can be achieved by providing feedback and the knowledge obtained from historical experience (Mobley, 2008).

In a modern organisation, it is recommended to break down the above three pillars into few more pillars, because that approach enable the companies to have better control on the implementation process of the TPM and moreover it enable the companies to measure the implementation progress more precisely. According to Rodrigues and Hatakeyama (2006), the definition of the pillars in TPM depends on the organisational structure that the company uses. However, in this thesis, we use the eight pillars that they suggested.

3.4 TPM modernized structure

According to Rodrigues and Hatakeyama (2006), the main eight pillars of TPM are the following:

1. Equipment and process improvement: This pillar aims to identify, resolve and prevent repeated problems or issues. The best approach to achieve this is to set up a cross-functional team which cooperates and proactively achieves regular enhancement in equipment operation without organisational boundaries (Vorne Industries Inc., 2017).

2. Autonomous maintenance: This pillar gives more responsibility and rules to the machine operators such as cleaning, lubricating and inspection. This approach is very beneficial because the operator’s knowledge level will increase, the equipment will be well-cleaned and lubricated and, moreover, the need for specialised maintenance personnel will be reduced.

3. Planned maintenance: This pillar aims to plan the maintenance work based on failure prediction. The approach reduces undesired stop time and provides a slot for maintenance work during the planned downtime; these two will bring about remarkable reductions in the inventory because the company will have better control of wear and tear of parts (Vorne Industries Inc., 2017).

4. Education and training: This pillar is very crucial because, as an example in the TPM, we are slightly changing the rule of the operators and, in order to achieve success, the knowledge gaps have to be filled in. Of course, the training will not be only for operators, the maintenance personnel will need to be trained in proactive and preventative maintenance. Also, managers need training on TPM principles (Vorne Industries Inc., 2017).

5. Early management of new equipment: Ultimately, the knowledge gained and the lessons learned from the experience with existing systems need to be considered during the acquisition of new equipment. This experience will contribute into modifying the design of the equipment or choosing alternative designs. These actions aim to improve the equipment performance and avoid past operational issues. The generic approach would be to select equipment that is almost maintenance free (ideal case) or requires only simple maintenance (Vorne Industries Inc.,2017).

6. Process quality management: This pillar aims to detect error or fault in the production process. Sequential actions are needed to prevent the fault occurrence, such as running a Root Cause Analysis using Ishikawa or the five whys technique. Obviously, these actions will lead to further reductions in the goods defects and, consequently, will reduce production costs (Vorne Industries Inc.,2017).

7. TPM in the office: This pillar aims to seek the necessary attention from management or the administration, which is needed during, for example, order processing, procurement and scheduling (Vorne Industries Inc.,2017).

8. Safety and environmental management: This pillar aims to maintain a safe and secure working environment. This can be achieved via a sequential set of actions that remove expected health and safety risks.

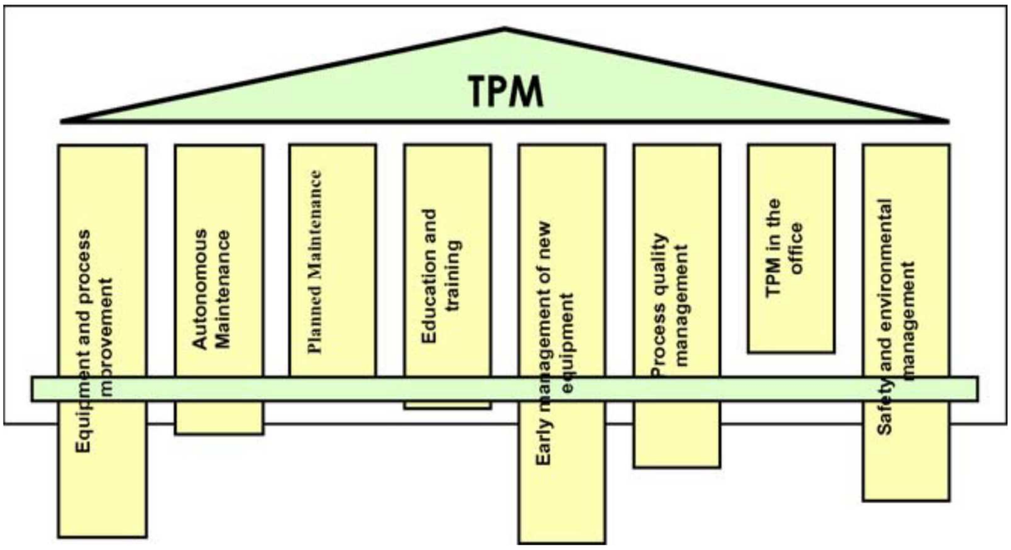


Figure 8: TPM's eight pillars by Rodrigues and Hatakeyama (2006)

3.5 TPM key aspects

This subchapter describes in details some of the key aspects of the TPM such as the 6s, six big losses, and OEE parameters and calculations.

3.5.1 The 6S steps

The first step in the implementation process of the TPM program is introducing the 5S or 6S method. The 5S/6S aims to maintain the workplace in a clean, safe, secure and most efficient manner. The 5S was the name of a working procedure that consisted of five actions summarized by five Japanese words - seiri, seiton, seiso, seiketsu and shitsuke – which, in English, mean sort, set in order, shine, standardise and sustain, respectively. This procedure was developed further by adding the safety perspective it to become the 6S(Wikipedia, n.a.).

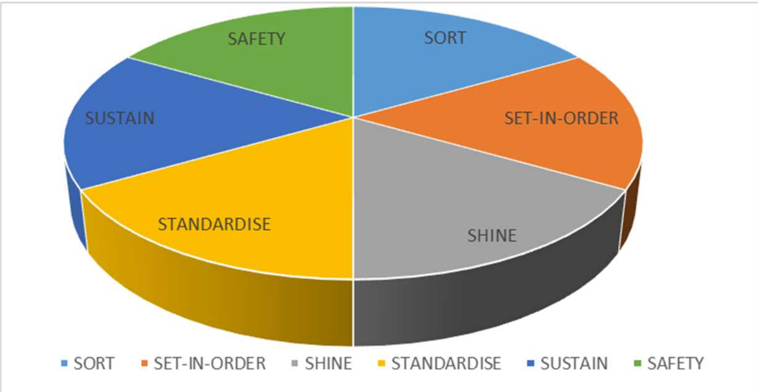


Figure 9: The 6S pie chart

The 6S steps are the following:

According to Brien (2015), the actions 6S procedures are the following:

SORT: This action practically means to remove all unnecessary items from the workplace and to define the necessary tools to carry out the tasks.

SET-IN-ORDER: This action practically means to organise the necessary tools in the best possible efficient way. **SHINE:** This action practically means to clean the workplace and to make sure that everything is in good order. **STANDARDISE:** This action practically means to adopt a systematic manner to perform tasks and procedures. **SUSTAIN:** This action practically means to continue repeating good habits and can be achieved by maintaining updates to the work procedures. **SAFETY:** This action is very crucial and aims to alert personnel to put safety first when they determine the item locations.

Figure 10 illustrates the existing 5S for Roxar

Loop	Empty dustbins & segregate waste responsibly
	Ensure chemicals are correctly stored and bunded
	Tidy up and wipe off workbenches
	Tools in and equipment in place
	Check floormarking. Repair if necessary
	Sweep floor

Figure 10: Roxar 5S system

Note: Roxar is using 5s and it recommended that Roxar modifies existing systems and starts to use the 6S which include the safety.

3.5.2 Six big losses

3.5.2.1 Standard six big losses

The TPM strategy is considered as a good management initiative which is needed in competitive markets. The TPM strategy urges companies to take firm actions towards eliminating waste, optimising equipment performance and reducing interruptions or stops of production. The TPM literature has defined the traditional six big losses as below and which are categorised into three main categories: category 1 is availability losses, category 2 is performance losses and, finally, category 3 is quality loss (Brien, 2015).

Downtime/Availability Losses: (1) Equipment Breakdowns and (2) Setup and Adjustment. (Brien, 2015).

Reduced Speed or Hidden/Performances Losses: (3) Idling and Minor Stoppages and (4) Reduced Speed. (Brien, 2015).

Defects/Quality Losses: (5) Process Defects and (6) Reduced Yield. (Brien, 2015).

Overall Equipment Effectiveness	Recommended Six Big Losses	Traditional Six Big Losses
Availability Loss	Unplanned Stops	Equipment Failure
	Planned Stops	Setup and Adjustments
Performance Loss	Small Stops	Idling and Minor Stops
	Slow Cycles	Reduced Speed
Quality Loss	Production Rejects	Process Defects
	Startup Rejects	Reduced Yield
OEE	Fully Productive Time	Valuable Operating Time

Figure 11: Traditional six big losses (Brien, 2015)

As per figure 11, the traditional six big losses have been renamed to what is called the recommended six big losses. The recommended naming is simple and more practical and can be easily understood and captured in any manufacturing industry.

The following section gives more insight about the meaning of each loss as defined by Brien (2015).

(1) Equipment Failure/Unplanned stops: This represents the time in which equipment is planned for operations, but is stopped because of any failure.

(2) Setup and Adjustments/Planned Stops: This represents the time in which equipment is planned for operations, but is stopped because of installation or uninstallation of the new product. Also, it can represent stops because of adjustment to other equipment. **(3) Idling and Minor Stops/Small stops:** This represents the time where the equipment stops for a short period, for example, a minute or two. This period should not be more than five minutes. **(4) Reduced Speed/Slow Cycles:** This represents the time when the equipment runs slower than the ideal. Many things can lead to reduced production speed, such as dirty or worn out equipment, bad lubrication and others. **(5) Process Defects/Production Rejection:** This quantifies the defective goods which are manufactured during the steady-state process. **6) Reduced Yield/Start-up Rejecting:** This quantifies the defected goods which manufactured during startup of the process.

3.5.2.2 Flow loop specific seven big losses

Seven big losses

1	Failure at any of Flow loop equipment
2	Setup and adjustments of the product
3	Calibration of flow loop instrumentatio
4	Test report
5	Faulty MPFM (product issue)
6	Others losses (general power loss)
7	Configuration change

Figure 12: The flow loop seven big losses

Brainstorming sessions were held with the loop operator and manufacturing engineer in order to determine the specific big losses for the flow loop. These personnel deal with the loop on a day-to-day base and are the most sensitive personnel to the operation of the flow loop. These brainstorming sessions were held twice, with each session lasting for one and a half hours. The outcome of these brainstorming sessions was seven big losses. These losses are described in detail in the following section and shown in figure 12:

1- **Failure at any of flow loop equipment**. This represents the period in which equipment is scheduled for operations, but is not running due any failure.

2- **Setup and adjustments of the product:** This represents the time in which equipment is planned for operations, but is stopped because of installation or uninstallation of the new MPFM. Also, it can represent stops because of adjustment to other equipment.

3- **Calibration of flow loop instrumentation:** This represents the time used to calibrate and verify the performance of the reference equipment and/or any other instrumentation of the flow loop.

4- **Test report (Correction and calculation):** This represents the time used to write a report of each test. During this time the operator stops the loop and trends the MPFM data versus the reference instruments in order to determine any uncertainty in the readings.

5- **Faulty MPFM (product issue):** This represents the lost time because of any issues related to the tested MPFM.

6- **Others losses (general power loss, operator sickness):** This represents the lost time because of any other issue, for example, a power cut or other circumstances that lead to the stopping of the loop

7- **Loss due to configuration change**: This represents the time lost when changing the configuration of the loop. The company runs six different types of flow tests. Each test requires some setup changes in the loop and this is considered a loss. These tests are: top-side MPFM (standard test); subsea MPFM; rent out the loop to another; qualification test of new MPFM; and qualification test for new software

3.5.3 Overall Equipment Effectiveness (OEE)

The OEE is a common KPI that is used for measuring the effectiveness of equipment. The concept of OEE is quite simple because it gives a live comparison between the best possible OEE and the actual OEE. The best OEE is achieved by making only good parts, at full speed, with no stops. One of the main goals of TPM is to maximise equipment effectiveness by reducing the waste in the manufacturing process. The three factors that determine equipment effectiveness are equipment availability, performance efficiency and quality rate and are used to calculate the equipment's overall equipment effectiveness (OEE) measure The OEE is calculated by multiplying the availability by the performance and the quality of the equipment.

AV X PE X QT = OEE

3.5.3.1 Equipment Availability

The availability is the ratio between Run Time and the Planned Production Time, meaning that it is equal to the **Run Time/Planned Production Time** (Brien, 2015).

A good company will try to have the production equipment available for use when it is needed. Obviously, this doesn't mean that the equipment must always be available. In some cases, there is little benefit to having equipment up and running when the products aren't needed. However, if there is a need to increase the production rate, the equipment must meet the demand increase.

The most common cause of lost equipment availability is unexpected breakdowns which impact the maintenance personnel who must get the equipment back to its up and running status as quickly as possible. Moreover, it impacts the equipment operator who needs the equipment to be repaired to continue working (Mobley, 2008).

One way to minimise the effect of lost equipment availability is keeping backup systems available. However, this is a very costly approach since it requires investing in inventory. The company management must balance between the costs of keeping the potential utilisation of the equipment high versus the costs of having inventory. Another loss of the equipment availability is the time required to change-over the equipment to run different products. This setup time is often overlooked, even though it has the potential to eliminate a significant amount of non–value added time (Mobley, 2008).

3.5.3.2 Performance

The equipment performance is a commonly used measurement when evaluating a manufacturing process. The performance is typically maximised by running the equipment at its highest speed for as long as possible (Mobley, 2008).

However, the performance is reduced by the time when the equipment is waiting for parts to load (idling) and time lost to make small adjustments to the equipment.

Based on this, the performance can be defined as the ratio of Net Run Time to Run Time while the Net Run Time can be calculated by multiplying the Ideal Cycle Time by the Total Count. Consequently, the performance is equal to the multiplying of the Ideal Cycle Time by the Total Count and is divided over the Run Time (Brien, 2015).

It should be noted that the Ideal Cycle Time is the fastest cycle time that the process can be achieved in optimal circumstances, while the Total Count represent the number of the produced parts, regardless whether these parts are passed or rejected through the quality control process

3.5.3.3 Quality Rate

The purpose of the manufacturing system is not to run equipment just to keep people busy operating it; the purpose is to make useful products. If the equipment is available and operating at its designed speed, but is producing poor quality parts, then there is no real value of running the equipment. In this case, it is better to shut the equipment down to save energy and raw materials and repair it. Obviously, it is, therefore, important to measure the quality of the equipment (Mobley, 2008).

The quality considers manufactured parts that do not meet quality standards, including parts that need reworking. Quality is calculated by dividing the Good Count and Total Count. The Good Count is defined as the parts that pass the quality control process (Brien,2015).

3.5.3.4 Consideration during the OEE data gathering

During the design of the OEE calculation sheet, the following have been avoided (Linkedin, 2014):

- Focusing on OEE number, not on the underlying losses: The OEE number does not help without understanding the underlying losses. Identifying the losses and the causes of the losses and the methodology to avoid or mitigate these losses is the only way to improve the production
- Using the planned production time as the Ideal Cycle Time, which is longer than the true Ideal Cycle Time, which is the maximum theoretical speed of the process.
- Allowing or accepting the loss: A strict procedure needs to be developed when collecting the losses and means that everything that makes sense has to be included. The objective of OEE is to help you identify improvement opportunities; therefore, management should be very careful to exclude losses from the OEE calculation because visibility will be lost and that could be an improvement opportunity.
- Collecting too much data: The technician’s job is to operate the loop not to collect detailed data.

3.5.3.5 Flow loop OEE calculation challenges and proposed solution

The flow test of the MPFM is a lengthy process and it is not similar to high volume manufacturing process whereby a machine produces many parts per day. The flow loop is a low volume manufacturing process; for example, one flow test is completed per week. Therefore, measuring the performance of this process is very challenging without breaking down the flow test process. Thus, the process has been broken down to several stages, whereby the Ideal Cycle Time and Total Count and the Good Count for each part of the process are calculated separately.

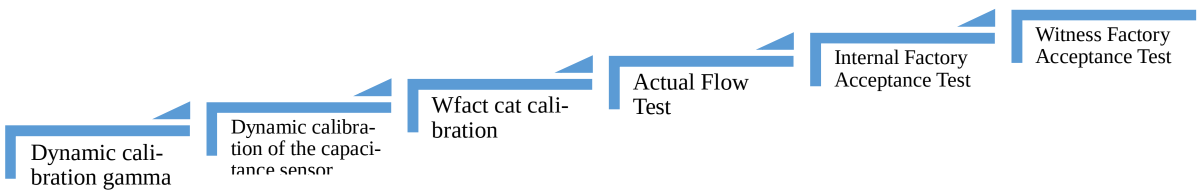


Figure 13: The flow test process description

The flow test process consists of several stages as per figure 13. The first stage after installation is the dynamic calibration of the gamma source, the second stage is the dynamic calibration of the capacitance sensor and the third is the water fraction calibration, the fourth is the flow test, the fifth is the internal factory acceptance test and the last stage the wit-ness factory acceptance test.

4 Spare parts management

Spare parts planning and management are considered as very critical tasks in asset management and it is crucial to keep a number of spare parts, as many as needed, in order to minimise down-time. On the other hand, it should be as low as possible in order to minimise spare parts holding costs So, spare parts planning and management should be carried out according to a scientific basis, which will be discussed later.

Several parameters contribute to the decision as to which spare parts we should buy and how to optimise the quantity of spare parts that should be bought. The manufacturing procedures are the main source of information about which part has to be bought and how many pieces are required of each part per year.

Once the required spare parts have been identified, subsequently, the number of pieces to be ordered straight away should be determined. The decision of keeping a particular spare part mainly depends on the criticality of the part itself and its effect on all of the equipment, system, and the entire facility. So, a criticality assessment should be carried out in order to classify those parts according to their significance. Figure 14 shows the spare parts risk analysis.

		Part Criticality								
		Catastrophic			Significant			Insignificant		
Frequency of Failure	Frequent	100	100	100	95	85	80	75	70	65
		100	100	95	85	80	75	70	65	60
		100	90	85	80	75	70	65	60	55
		90	85	80	75	70	65	60	55	50
		85	80	75	70	65	60	55	50	45
	Moderate	80	75	70	65	60	55	50	45	40
		75	70	65	60	55	50	45	40	35
		70	65	60	55	50	45	40	35	30
		65	60	55	50	45	40	35	30	25
		60	55	50	45	40	35	30	25	20
	Infrequent	55	50	45	40	35	30	25	20	15
		50	45	40	35	30	25	20	15	10
		45	40	35	30	25	20	15	10	5
		40	35	30	25	20	15	10	5	0
		35	30	25	20	15	10	5	0	0

Figure 14: Spare parts risk analysis (www.lce.com, 2011)

Figures 15 and 16 illustrate the spare parts in terms of criticality level, the lead time level and the holding cost curve versus the ordering curve, respectively.

Lead time \ Criticality	Low	Mod-erate	High
Short	S_{SL}^{*}	S_{SM}^{*}	S_{SH}^{*}
Moderate	S_{ML}^{**}	S_{MM}^{**}	S_{MH}^{***}
Long	S_{LL}^{**}	S_{LM}^{***}	S_{LH}^{***}

Figure 15: Spare parts criticality and lead time matrix

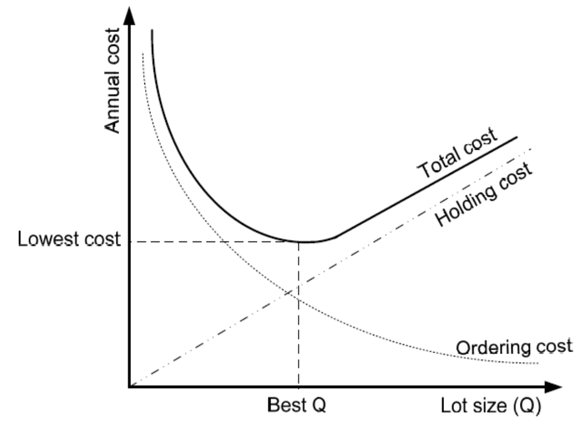


Figure 16: Holding cost curve versus the ordering curve

Once usage lead times, availability, costs, interest rates, storage costs, inflation and chance of spoilage have been taken into consideration, economical order of quantities should be determined and inventory control procedures should be incorporated

5 Life cycle calculation

Making a selection between various alternatives of equipment that will perform the same functions is one of the most challenging tasks that will face the asset managers in the event of replacing or ordering equipment to be changed. It is required to evaluate that equipment separately with respect to its capital and operational costs, as well as deferred production cost. The purpose of this evaluation is to provide a good estimation about the equipment cost during the entire lifetime or a specific number of years. This evaluation in the context of asset management is called Life Cycle Cost analysis (LCC). LCC is a tool used to compare between two or more alternatives in order to select one of them. The selection criteria between those alternatives is the cost-effectiveness, which represents a combination of cost and the expected benefit of each solution. LCC should be done in conjunction with risk analysis for the sake of ensuring safe and reliable operation of the selected equipment. The “NORSOK standard O-CR-002” used in performing the LCC analysis is illustrated in the Appendix D.

6 Methodology

6.1 Introduction

According to the J Exp Bot, In February 2002, Donald Rumsfeld, the former US Secretary of State for Defence, stated that‘There are known knowns. There are things we know that we know. There are known unknowns. That is to say, there are things that we now know we don't know. But there are also unknown unknowns. There are things we do not know we don't know. I think Donald Rumsfeld statement is correct because there are known unknowns and unknown unknown’s issues and that is why we should do the necessary efforts to discover these known unknowns and unknown unknowns issues. During the research and the study of the industrial asset management programme, I have studied about the five-collective mindfulness and about how the systematic use of these principles enable us to discover known unknowns and unknown unknowns issues. These five-collective mindfulness principles are: (1) the preoccupation with failure, (2) the reluctance to simplify, (3) the sensitivity to operations, (4) the commitment to resilience and (5) the deference to expertise. These principles can be divided into two main categories; the first aims to expect unexpected issues, while the second group aims to contain these issues. High reliability companies constantly observe, monitor /control and evaluate failures, near misses and the indication of problems. Therefore, these types of thinking enable companies to expect the unexpected. Moreover, these companies see the necessity to enhance routines and seek the help of expertise in order to plan how to contain such unexpected issues (Aanestad and Jensen, June 2016 pp. 13-27).

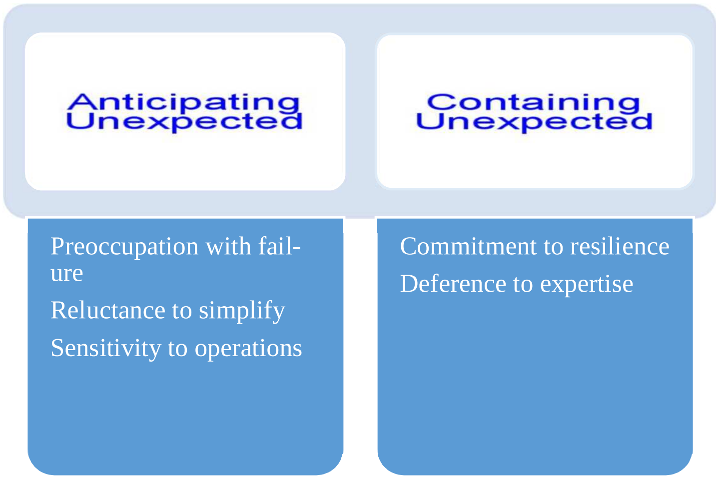


Figure 17: Five-collective mindfulness principles (Aanestad and Jensen June 2016 13-27)

These principles are very important, not only in the industrial asset management industry but also in normal life. Any person who applies these principles is likely to achieve a high percentage of success over their entire life. According to the blog, Heartwood Refuge Retreat Center Benefits of Mindfulness, concerning the advantages of using mindfulness at work, persons will become more efficient, focus on task, communicate better with colleagues, become a good leader, accept the criticism and be a better listener, while, in education, the advantages of mindfulness are increasing the ability learn, enhancing observation, developing the emotions and enhancing grades and behaviour Moreover, through the Saybrook University the blog, Mindfulness and The Bottom Line, the use of mindfulness will make personnel less reactive and more proactive, which converts to better analysis and awareness and it improves the quality of decisions. Therefore, in this thesis, the focus was to build few systems such as the OEE and the seven big losses tracking system and equipment criticality ranking system that enables the management to take a decision based on factual and scientific approach.

6.2 Thesis working process.

Figure 18 illustrates the thesis activities flow chart. This thesis started with a basic research and study whereby I read through many thesis with similar or closely related subjects and other sources. The second step was the objectives identification that is why many meetings were held with external supervisor Mr. Jan Inge in order to set a clear objectives and deliverables for this thesis. The third step was conducting a site survey on the flow loop in order to be conscious of the loop equipment, structure, and operation. The fourth step was to break down identified objectives into a tangible, measurable and achievable sub-objectives. Therefore, I developed a system that captures and visualises the OEE and seven big losses; I developed a quantitative analysis to rank the flow loop equipment with respects to their in on the loop functionality; I developed an implementation plan. The fifth step was gathering and discussing data with Professor Knut and Mr. Inge. Finally, I developed a set of recommendations and the conclusion.

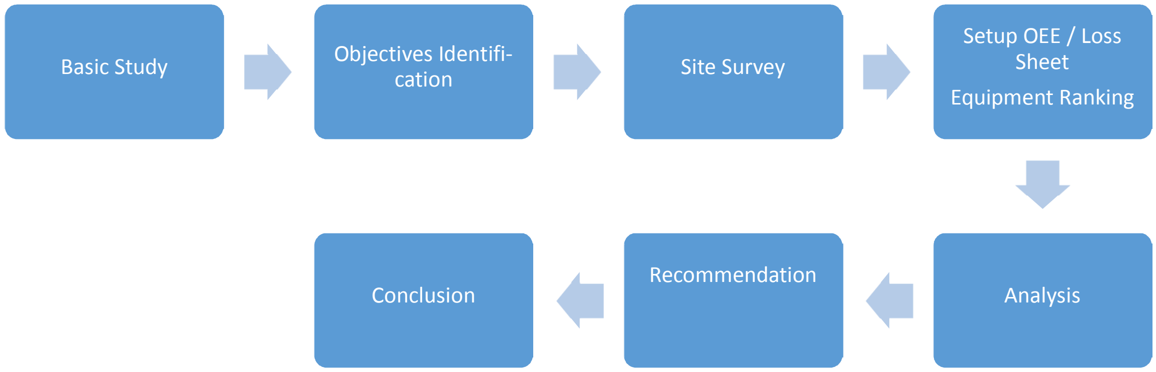


Figure 18: Thesis working process flow chart.

6.3 Research on the TPM

Many of the subjects that had been studied during the industrial asset management master program contributed to the research of this thesis, mostly the operations and maintenance, condition monitoring, project management and risk assessment. I spent one month reading through the TPM literature and about companies which specialised in implementation, such as Productivity Inc., focusing on the TPM material that Emerson has and several meetings with the Roxar operations director, manufacturing engineer and operators were scheduled.

6.4 Evaluating TPM initiative and equipment conditions in Roxar

Two forms developed by a company called Productivity Inc. were used in the evaluation of the TPM initiative and the equipment status.

The first form was used to evaluate the eight pillars of the TPM initiative and these pillar are the following (1) equipment and process improvement; (2) autonomous maintenance; (3) planned maintenance; (4) education and training; (5) early management of new equipment; (6) process quality management; (7) TPM in the office; and (8) safety and environmental management. The scoring criteria of each pillar is described in more detail in the data collection chapter of this thesis (Productivity Inc. *TPM progress scan*).

The second form was used to evaluate the technical status of all the equipment of the flow loop. This form gives rating to the electrical system, lubrication system, workstation, pneumatic systems, etc. This form is a generic form and thus many of its sections are not applicable for the flow loop (Productivity Inc. *TPM equipment scan*).

6.5 Developing OEE and seven big losses system

In this section, a system in excel sheet base has been developed which consists of the following three main sections: the event stop log section; the big losses calculations section; and the OEE calculation section.

The first section is the stop log which shows the stop date and duration, and reason of the stop. More details are given in the data collection chapter of this thesis. The second section is about the big losses which visualises the losses and it types and the losses percentage with respect to the overall operating time of the flow loop at this point of time. More details are given in the data collection chapter of this thesis. The third section is the OEE calculation which visualise the three core parameters of OEE which are availability, performance and quality of the flow loop. It also shows the sub parameters used in calculating the OEE main parameters.

6.6 Ranking and prioritising equipment with quantitative analyses

The Norsok Standard Z-008Rev. 2 November, 2001 provides a good guide to develop the quantitative analysis which used to rank the flow loop equipment. The initial step was break down the flow lop according to the main functions, then it followed by step to determine the equipment of each of the main functions. The third step was evaluating how each equipment impacts the availability, performance and quality of the flow loop. The evaluation was based on a score from 1 to 5 for availability, performance and quality, where equipment with 1 has the lowest impact and equipment with has the highest impact. The impact on the availability, performance and the quality were given the same rating weight. Final step was to selected the maximum scores in from each of availability, performance and the quality and classified the maximum score into four categories critical, serious, neutral and minor. More details available in the data collection chapter of this thesis

6.7 Suggested TPM implementation methodology

The project management (PM) discipline has been developed in a context of industry activities and natures. If project goals, tasks, interdependencies and sequences are well-defined, then the common or traditional PM methodology is the best tool for this project. However, the history of projects tells that many projects have fuzziness about project goals and solution. Consequently, the traditional project management that assumes known and well-defined is not well suited for these types of projects (Wysocki, 2009).

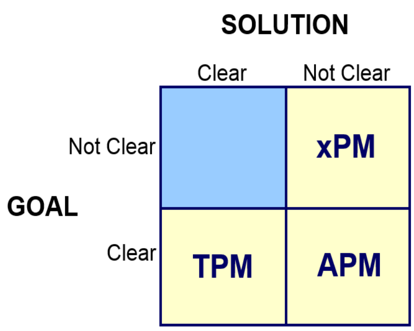


Figure 19: Project Management Models

There are many Project Management Life models, such as the traditional models (TPM), agile models (APM), extreme models (XPM) and the «Emertxe Project Management» (MPX). As shown in Figure 19, there are two perspectives for the fuzziness profile. The first is goal fuzziness, while the second is solution fuzziness. Therefore, the choice of the best project management model depends on the fuzziness profile of the projects. For example, if the goal is clear, but the solution is not, then the agile model (APM) is the recommended model for this project (Wysocki, 2009).

In general, the implementation process of the TPM programme is a lengthy process and it may take three years or even more. Furthermore, it is not clear at the start of the implementation process as to the level of preventative maintenance, autonomous maintenance or the training that meets the company real needs, which means that the solution is not clear, but the goal to implement the TPM is clear. Therefore, these factual statements push towards utilising the agile project manage methodology, particularly the adaptive project management life cycle, in implementing the TPM for the flow loop. The agile project management consists of two methodologies which are the Iterative Project Management and the Adaptive Project Management. The key section criteria of which methodology should be used is uncertainty or the fuzziness degree of the project's solution. It is known that the Adaptive Project Management methodology can accommodate projects with larger degree of uncertainty with regards the project solution.

7 Data collection

7.1 Evaluating the TPM initiative

The evaluation was performed using a form developed by Productivity Inc and this can be found in Appendix A. In the figure20, the lowest criteria and the highest criteria for each pillar of the TPM are given. As an example, if we take the focused improvement, the lowest score is 1, which means No OEE data are collected and the highest score is 5, which means 85 % OEE is achieved and zero losses are reported (Productivity Inc., TPM progress scan).

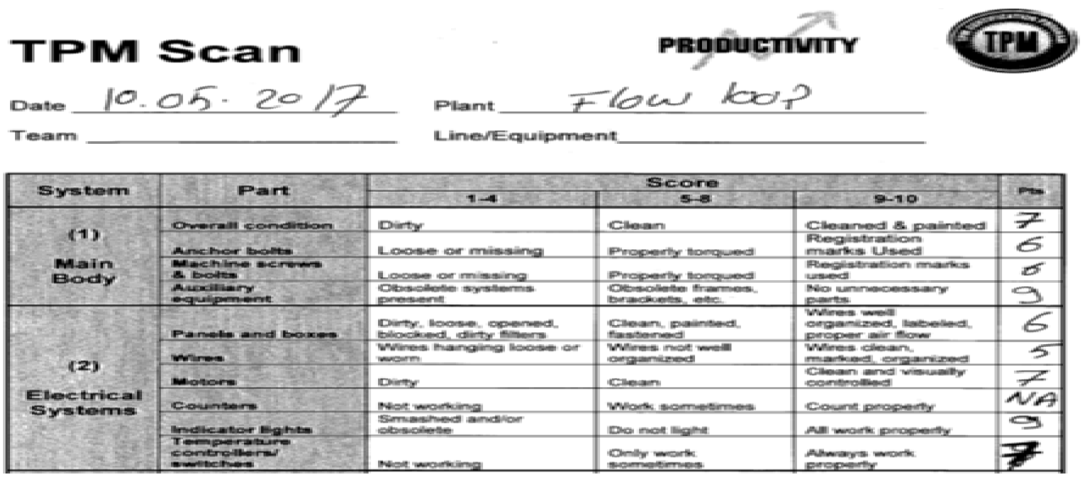
Figure 16 below shows the lowest and highest score for each of the TPM eight pillars.

	TPM 8 piller	Lowest score (1)	Highest Score(5)
1	Maint Improv	90% of maintenance is reactive	90% of maintenance is proactive
2	Auton Maint	Operators “run” equipment; maintenance “fixes it	Operators own 7 steps of Autonomous Maintenance are in place
3	Focused Improv	No OEE data collected	85% OEE and Zero Losses reported
4	Safety	Numerous safety incidents occur annually	Safety incident rate is benchmark for your industry
5	Training	No training matrix in place for operators and maintenance personnel	Training matrix in place; 90hrs/ year for skill en-hancement
6	Quality Maint	Quality issues are addressed by Quality Assurance Dept.	Sigma level and higher consistently reported (when incidents occur they are handled at the source
7	Early Equipment managt mainat	No life cycle cost data being collected	Life cycle cost (and cross functional teams) used to design/ acquire new equipment
8	Office TPM	No involvement by Administrative departments in the day-to-day equipment improvement	Admin departments participate in TPM activities 85% O

Figure 20: Scores weighting TPM eight pillars (Productivity Inc., TPM progress scan)

7.2 Evaluating equipment conditions

The evaluation is performed using a form developed by Productivity Inc. and is called form TPM SCAN ON EQUIPMENT. This form is filled in together by the loop operator and the manufacturing engineer. The completed form can be found in Appendix B.


TPM Scan

PRODUCTIVITY

TPM

Date 10.05.2017 Plant Flow loop

Team

Line/Equipment

System	Part	Score 1-4	Score 5-8	Score 9-10	Pts
(1) Main Body	Overall condition	Dirty	Clean	Cleaned & painted	7
	Anchor bolts	Loose or missing	Properly torqued	Registration marks Used	6
	Machine screws & bolts	Loose or missing	Properly torqued	Registration marks used	6
	Auxiliary equipment	Obsolete systems present	Obsolete frames, brackets, etc.	No unnecessary parts	9
(2) Electrical Systems	Panels and boxes	Dirty, loose, opened, blocked, dirty filters	Clean, painted, fastened	Wires well organized, labeled, proper air flow	6
	Wires	Wires hanging loose or worn	Wires not well organized	Wires clean, marked, organized	5
	Motors	Dirty	Clean	Clean and visually controlled	7
	Counters	Not working	Work sometimes	Count properly	NA
	Indicator lights	Smashed and/or obsolete	Do not light	All work properly	9
	Temperature controllers/ switches	Not working	Only work sometimes	Always work properly	7

Figure 21: Sample of the form used in evaluating the loop equipment (Productivity Inc., TPM equipment scan)

7.3 OEE and seven big losses system designing

Prior the kick-off if this thesis, there was no existing system in Emerson/ Roxar to gather data of the OEE parameters and consequently the OEE was not calculated. Moreover, there was no existing system that enables Emerson/ Roxar to identify and capture the flow loop losses. Based on these facts, one of the key objectives of the thesis is to develop a dashboard. The dashboard has been developed throughout the thesis which enables Emerson/Roxar to captures and visualises the seven big losses as well as TPM implementation progress. Moreover the developed dashboard Emerson/Roxar to captures, calculates and visualises the OEE and it is associated three key parameters availability, performance and quality. Figure 20 shows the flow loop OEE and seven big losses.

Figure 22: OEE/big losses dashboard (Ottosson, 2009)

7.4 Ranking and prioritizing equipment with quantitative analyses

The Norsok standard Z-008 methodology to identify criticality has been used partially in the critically analysis for the equipment of the flow loop. Each plant system should be divided into several main functions covering the entire system. The main functions are characterised by being principal tasks, such as heat exchanging, pumping, separation, power generation, compressing, distributing, storing, etc.

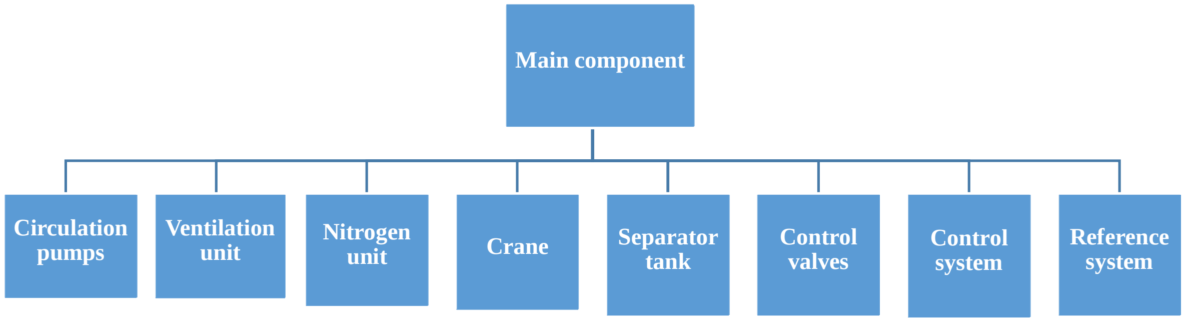


Figure 23: Main functions of the flow loop (Norsok standard Z-008)

Roxar has a premade list of many of the equipment and instruments that are located inside the flow loop. Although the list does not include all existing instruments, it has been used as the foundation for the criticality quantitative analysis.

There are many criteria-weighting models. However, in this application, the following criteria-weighting, as identified by Wysocki (2009), have been used.

The impact of each equipment on the availability, performance and quality of the flow loop has been assessed individually. These three categories were rated from 1 to 5 where 1 means that the instrument has least impact and 5 has the maximum impact on the availability, performance and quality of the flow loop.

After completing the rating, the maximum rating among the three categories has been selected to represent the criticality of the instrument. Figure 20 shows a sample of the ranking template. The detailed template is available in Appendix c.

12.3 Three phase equipment list classified

Critical Equipment									
Asset Number	Asset Description	Location	Spare parts	Impact on availability	Impact on performance	Impact on quality	Criticality	Maximum	Failure Likel
MAS-CB-01	Filter Type: Kaeser FFG-28 B S/N:1405	Compressor	No	5	5	5	15	5	
MAS-CB-02	Filter Type: Kaeser FE-28 S/N:6991	Nitrogen unit	No	5	5	5	15	5	
MAS-CB-03	Cyclone Type: Kaeser ZK072 S/N:398369360004	Separator tank	NA	5	5	5	15	5	
MAS-CB-06	Drain separator Type: Kaeser Aquamat CF38 S/N:3087	Compressor	No	5	5	5	15	5	
MAS-CB-07	Filter Type: Kaeser FG28 S/N:N/A	Compressor	No	5	5	5	15	5	

Figure 24: Sample of the ranking template

8 Evaluation and data analysis

8.1 Evaluating TPM initiative

This exercise is very useful because it evaluates where the company is in the TPM process. The evaluation helps considerably in determining the maturity level of the TPM process. Moreover, it helps in determining the true start point for the thesis in order to avoid duplicating the already performed work. (Productivity Inc., TPM progress scan).

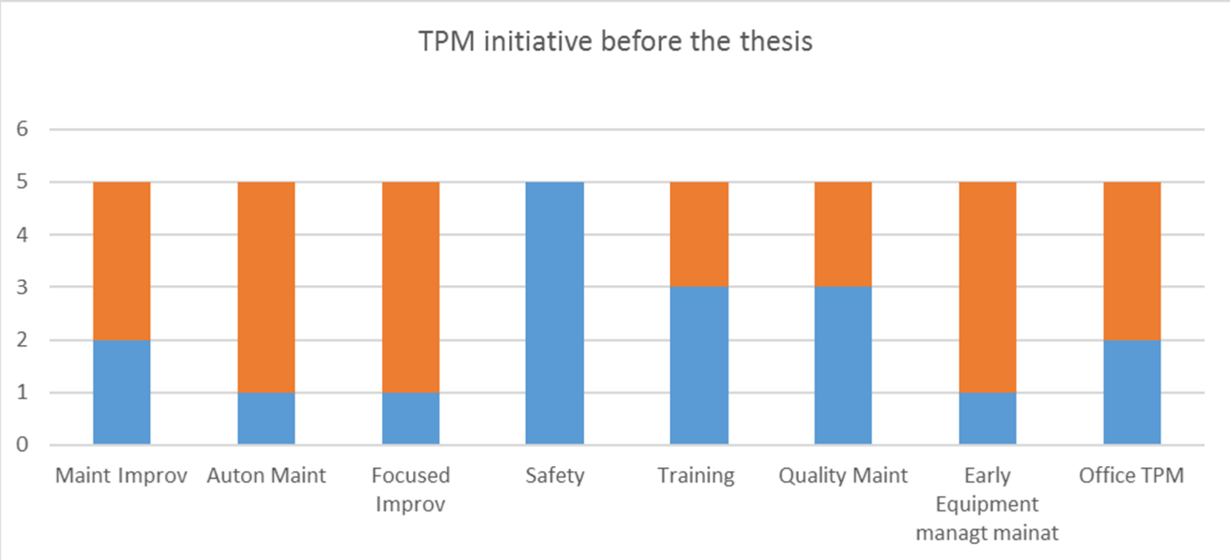


Figure 25: TPM initiative prior the thesis (Productivity Inc., TPM progress scan)

In the above stacked column chart (Figure 25 TPM initiative prior the thesis) the blue color shows Roxar scores in each pillar of TPM, while the orange color shows what is remaining and the summation of both the blue and the orange is equal to 5, which is the overall score range on each pillar.

The TPM initiative within Roxar can be evaluated as follows:

(1) Maintenance Improvement: Roxar scored 2 because 90% of maintenance is reactive.
(2) Autonomous Maintenance: Roxar scored 1 because operators “run” equipment, but maintenance “fixes” it. It must be mentioned that Roxar does not have a dedicated maintenance personnel for the flow loop and the needed maintenance is outsourced.
(3) Focused improvement: Roxar scored 1 because of No OEE data collected.
(4) Safety: Roxar scored 5 in this pillar because the safety incident rate is very close to being a benchmark for similar industry.
(5) Training and Skill Development: Roxar scored 3.
(6) Quality Maintenance: Roxar scored 3.
(7) Early Equipment Management/Maintenance Prevention Design: Roxar scored 1 in this pillar because there was No life cycle cost data being collected.

(8) Office TPM: Roxar scored 2 because the involvement of administrative departments in the day-to-day equipment improvement is not very extensive.

There are two main remarks on this pillar:

- First, Roxar's existing quality and safety polices are very good and they are close to being a benchmark compared to similar industry.
- Second, Roxar has not kicked off the TPM activities in the five pillars, which are Maintenance Improvement, Autonomous Maintenance, Focused Improvement, Early Equipment Management/Maintenance Prevention Design and Office TPM.

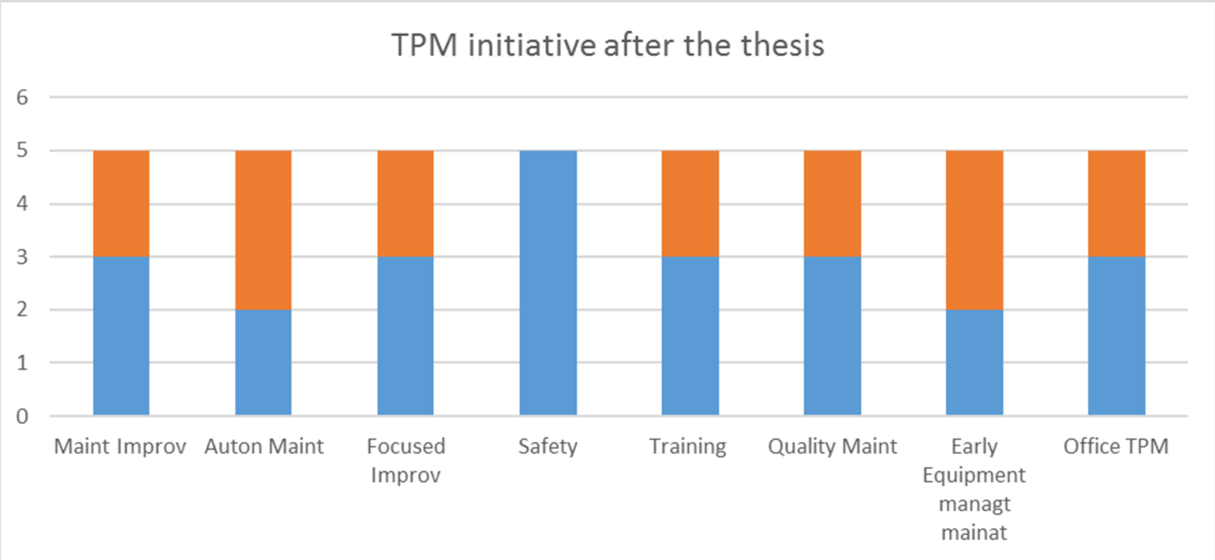


Figure 26: TPM initiative post the thesis (Productivity Inc., TPM progress scan)

In the above stacked column chart (Figure 26 TPM initiative post thesis) the blue shows Roxar scores in each pillar of the TPM while the orange shows what is remaining and the summation of both the blue and the orange is equal to 5, which is the total score on each pillar.

The thesis focused on doing background work for the four main pillars, which are Maintenance Improvement, Autonomous Maintenance, Focused Improvement and Early Equipment Management Maintenance.

- Maintenance Improvement: the critical equipment has been identified and this is a solid foundation to determine the best possible maintenance strategy for each instrument in the flow loop and as well as the best spare parts strategy for these parts.
- Autonomous Maintenance: Some improvement has been identified, likewise scheduling leakage inspection for the process area and the yearly or bi-yearly tightening of the screws and other connections for the loop.

- Focused Improvement: There was no OEE gathering. A system and procedure have been developed which is used to calculate and visualise the OEE and the seven big losses. In this system , the main parameters of the OEE, which are the availability, performance and quality, have been visualised.

- Early Equipment Management Maintenance: The methodology of the life cycle calculation has been shown in the recommendation section. This methodology was developed mainly by myself in exam report of subject OFF510 Operations and maintenance VÅR 2014. The methodology was in accordance to the norsok standard and an example was given as to how to select between two pumps alternatives.

- There is some improvement done on the training and office TPM pillars. As shown in the overall thesis, many meetings have been held between the manufacturing engineer and manufacturing team members. These meetings touched on what the TPM looks like and what will be the future roles for operators and considered hands-on training. Moreover, the mentioned team, which is likely to be the TPM team, has been actively engaged in the programme.

The figure 27 stacked column chart below illustrated the progress of the thesis on each pillar. The orange columns represent rating post the thesis and the blue represent the rating prior the thesis.

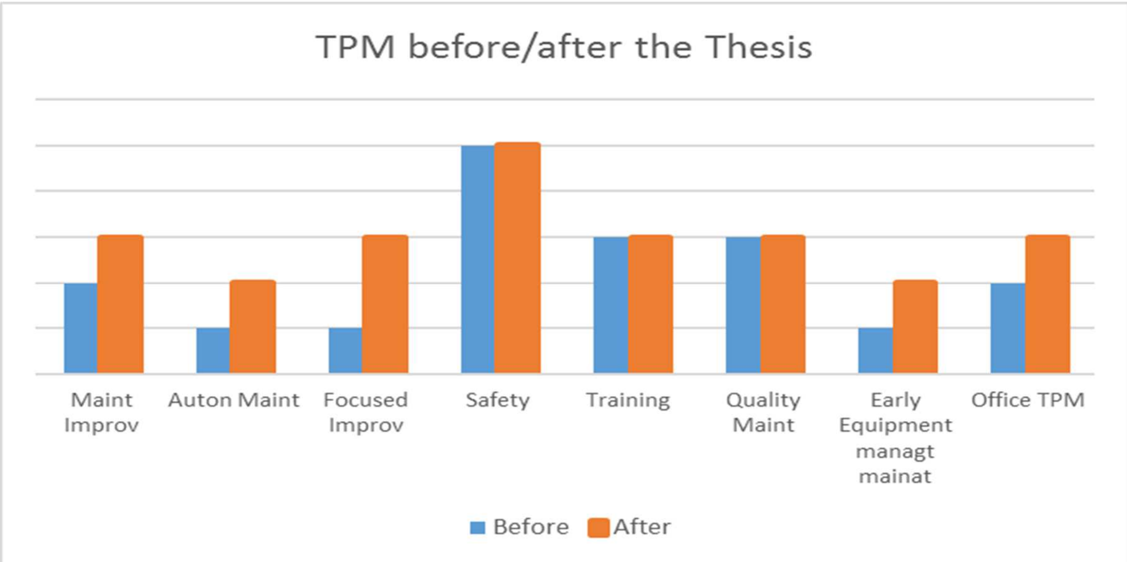


Figure 27: Comparison between the TPM initiative prior and post the thesis

8.2 Evaluating equipment conditions

In the appendix BB, the actual score on the flow loop has been captured. In this form the TPM total scan is 177 and number of the used line are 27. According to the formula that is developed by productivity Inc., the status score is calculated by dividing the sum of total score over (the number of lines multiplied by 10) *100. (Productivity Inc. TPM equipment scan)
The three phase flow loop achieved the following 177/(10*27) around 66 %.

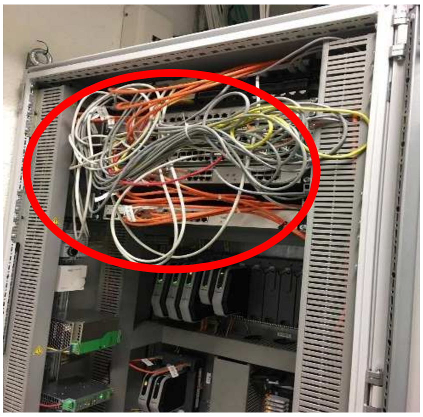


Figure 28: An example of potential improvement

According to Productivity Inc., if the score is around 85 % then the company has opportunity to save money and value can be added with TPM. It is rational to assume that Productivity Inc.'s business is encouraging companies to consult with them regarding the implementation of a TPM programme. That is obvious when Productivity Inc.'s,which is 85 %. However, in the flow loop, the actual scores were around 65 % , which indicates that there are possible improvement opportunities that can be achieved, especially for the points which scored 6 and lower.

These points are mainly in the workstation, around the separator tank and the electrical system. As an example, as seen in Figure 28, the wiring of the delta v system is messy, which makes it very difficult to track which wire goes where and complicates the maintainability and increases the repair time.

8.3 OEE and seven big losses system designing

In Figure 29, the blue line is measured OEE while the orange line represents the Ideal OEE, which is very difficult to be achieved. Only data for 4 weeks have been collected and this is not enough to reach a firm conclusion. A correlation between Figure 29 and Figure 30 can give an indication of what is the most impacted factor on the OEE; this indicates that the performance is the main driver of the OEE, because the availability and quality factors are relatively stable.
achieved performance. I consider 60 % difference as very large change. However, if we consider the availability parameter, it changes between 65% and 75% which is fairly stable. If we consider the quality, it is constant 100 % in the collected data.
From figure 30, it is very clear that performance parameter has the most impact on the OEE. It is clear that the yellow line follows the performance columns.

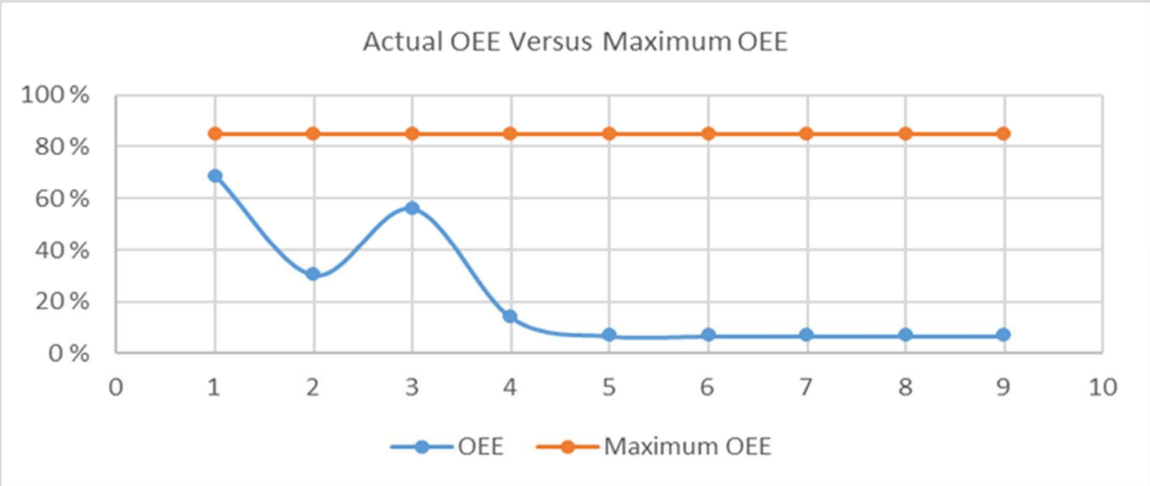


Figure 29: Actual OEE versus Ideal OEE

In Figure 30, the performance was 100% then it dropped to 40 % then increased to 75 % in weeks 17, 18 and 19 respectively which means there is 60 % difference between largest and lowest
The data form weeks 21 till week 25 is not valid data.

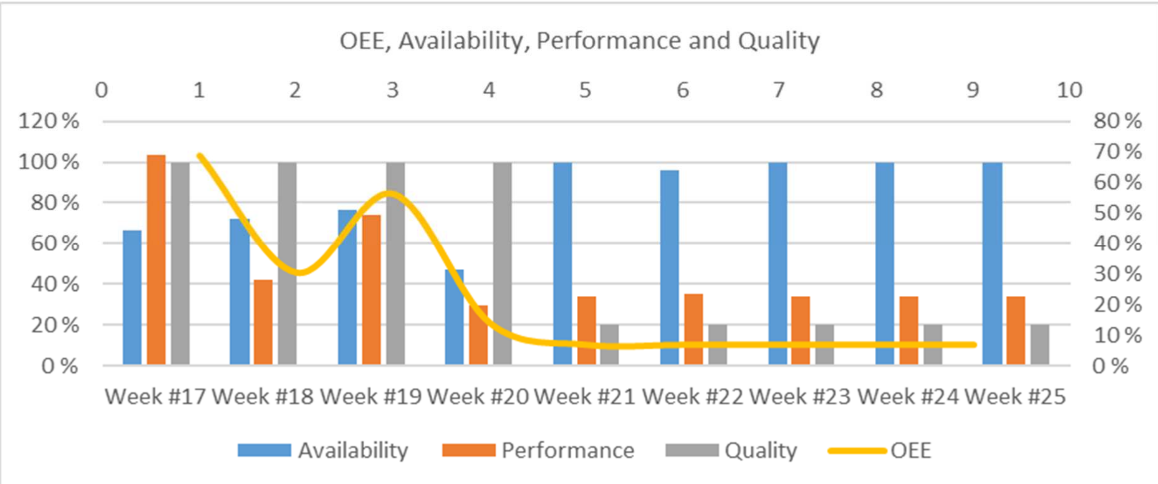


Figure 30: Actual OEE, availability, performance and quality

Figure 31, is the stop event log has been developed in order to capture the stop time and /or occurred availability losses. The log consists of five columns, which are the event sequence, followed by date, the reason number and stop description and, finally, the duration of the stop.

Figure 31 present the stop log for week 17 and we can notice the following

The operator used 90 minutes to write the reports, due to compressor issue the loop stopped for 30 minutes; there was power shortage and the loop stopped for 120 minutes.

	STOP EVENTS LOG			
	Date	Reason Number	Description	Duration in Minutes
1	24.04.2017	4	test report	30,00
2	25.04.2017	1	Commpressor	30,00
3	25.04.2017	3	zero cal coriolios	30,00
4	26.04.2017	4	test report	30,00
5	27.04.2017	6	power failure	120,00
6	28.04.2017	4	test report	30,00

Figure 31: Stop event log

The seven big losses stacked column chart (figure 32) visualises the percentage of operating time, failure loss, The seven big losses stacked column chart illustrates the percentage of operating time, failure loss, setup and adjustment loss, calibration loss, writing test report loss, faulty MPFM loss, configuration change loss and other loss. The colour coding of each category is mentioned in the lower section of the stacked column chart.
The summation of all the seven big losses and the operating time is equal to the total planned time, which is a variable parameter. Each column represents operating time and loss of a week. This stacked chart is good to illustrate the loss and, consequently, the management will take appropriate action to remove, mitigate or accept the loss as is. To date, four-weeks data have been collected, which is a short period and it is not sufficient to reach a firm conclusion. However, in week # 20 it is clear that the installation and the uninstallation of the MPFM takes around two days, which 40% of the weekly operating time. Obviously, some actions need to be taken in order to reduce the installation and the uninstallation loss.

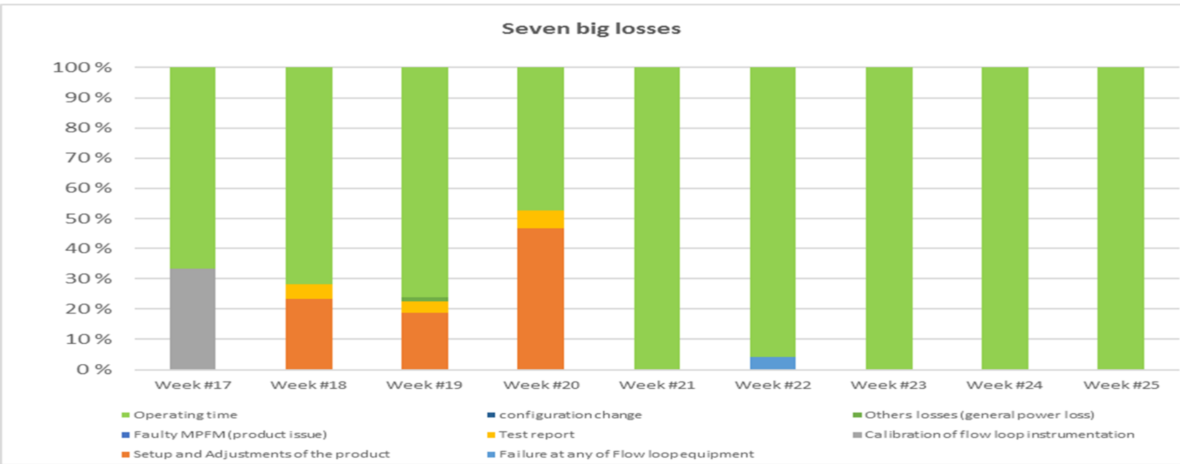


Figure 32: The seven big losses chart

8.4 Ranking and prioritizing equipment with quantitative analyses

There are three perspectives that should be considered during the execution of the criticality analysis. The first perspective is how critical is the equipment, while the second is the failure probability of the equipment. These two perspectives can be visualised in a risk matrix, as in figure 33, below

Risk Model

Failure Probability

Impact		Low	Medium	High	Imminent
	Critical	1	2	3	4
	Serious	5	6	7	8
	Neutral	9	10	11	12
	Minor	13	14	15	16

Figure 33: Risk matrix (Aven, 2011)

Some actions need to be taken concerning the equipment, which exist in the orange, red and yellow squares per priority order. These actions include preparing perceived maintenance, preventative maintenance, frequent visual inspection and also stocking up on some expensive spare parts. These actions have associated cons and are considered an investment.

That is why the third perspective should be assessed carefully. This is to carry out a cost benefit study with sensitivity analysis for these actions. The outcome or the pictures of these three perspectives will provide a clear picture and will help in taking the most cost-effective decisions. In this thesis, a quantitative analysis has been developed to answer the following question or perspective and partially touches on the second question.

8.4.1 Equipment criticality

According to the Norsok standard Z-008, the flow loop is divided into eight main areas and /or units, which are presented in the table below. The sub-equipment of the main areas and /or units are listed in Figure 34.

Main component	**Sub equipment**
Circulation pumps	- Centrifugal pump Type: Grundfos NB80-315/320 E-F-K-BQQ S/N:A98449852P213270003 - Centrifugal pump Type: Grundfos NB125-315/338 E-F-K-BQQ S/N:A98449769P213240001
Ventilation unit	- Gas transmitter Type: MSA PrimaX I S/N:a-08/13-02143 - Temp transmitter Type: Rosemount 248 DXI1D2NSWA3WK1B4Q4K1169 S/N:2547964 - Temp transmitter Type: Rosemount ??? Same as 62-TT1000 S/N:2547965

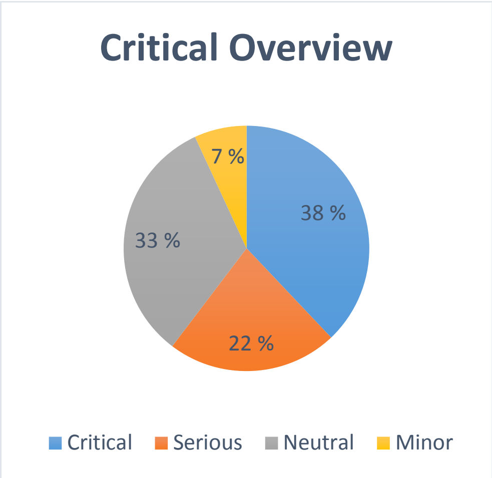
Nitrogen unit	- Gas transmitter Type: MSA PrimaX I S/N:08/13-02140 - Filter Type: Kaeser FE-28 S/N:6991 - Nitrogen Generator Type: Oxymat NITROMAT N350 ECO S/N:N2013072 - Condensate trap Type: Kaeser Eco - Drain 31 S/N:12600306 - Condensate trap Type: Kaeser Eco - Drain 31 S/N:1260305 - Condensate trap Type: Kaeser Eco - Drain 14 S/N:12483396
Crane	- Gantry Crane Type: Demag 2,5 t S/N: 41-1037
Separator tank	- Mixing of Saltwater in FlowLoop - Gas transmitter Type: MSA PrimaX I S/N:08/13-11566 - Gas transmitter Type: MSA PrimaX I S/N:08/13-02662 - Cyclone Type: Kaeser ZK072 S/N:398369360004 - Pressure transmitter Type: Rosemount 3051 TG3X2B21PWA3WP5B4I1M5P1Q4Q8 S/N:9452890 Liquid separator - Temp transmitter Type: Rosemount 648 DX1D1I1WA3WK1M5Q4XA S/N:2539698 Liquid separator
Control valves	- Actuator valve – Gas line - Actuator valve – Gas line - Actuator valve – Diesel line - Actuator valve – Diesel line - Actuator valve – Water line - Actuators valve -Water line - Actuators valve - Liq mix - Actuators valve - Liq mix
Control system	- Delta V Guardian Support agreement Model nr: VE9041S0200
Reference system	- Condensate trap Type: Kaeser Eco - Drain 14 S/N:12483396 - Coriolis Type: Micro Motion CMFS150M328N2FZNKZZ S/N: 12091878 - Coriolis Type: Micro Motion CMF300M355N2F6NZZ S/N: 14374988 - Coriolis Type: Micro Motion CMF300M355N2F6NZZZ S/N: 14377776 - Coriolis flow meter Type: Micro Motion CMF400M 451N2F6NZZZ S/N:14373079 - Coriolis flow meter Type: Micro Motion CMF400M 451N2F6NZZZ S/N:14283621 - Pressure transmitter Type: Rosemount 3051 TG3A2B21BI1M5P1Q4Q8 S/N:9452894 Gas Section - Pressure transmitter Type: Rosemount 3051 TG3A2B21BI1M5P1Q4Q8 S/N:9452891 3 Inc Mix - Pressure transmitter Type: Rosemount 3051 TG3A2B21BI1M5P1Q4Q8 S/N:9452892 6 Inc Mix

	- Pressure transmitter Type: Rosemount 3051 TG3A2B21BI1M5P1Q4Q8 S/N:9568827 3 Inc / Test unit A - Pressure Transmitter Type: Rosemount 3051 S/N: 7303040/0699 Old: RFM-774-135 6 Inc /Test unit C - (Spare) Pressure transmitter Type: Rosemount 2088 G2S22A2S1E5O4 S/N:9182900 - Temp Transmitter Type: Rosemount Pt100 S/N: 02539697 S/N #2: 03395801 Tag: TT3012 3 Inc / Test unit A+B - Pressure Transmitter Type: Rosemount Model 3051 0-10Bar S/N: 9452893 3 Inc / Test unit B - Temp transmitter Type: Rosemount 644 HAI1XAJ6M4Q4 S/N: 02539695 Gas Section - Temp transmitter Type: Rosemount 644 HAI1XAJ6M4Q4 S/N: 02539696 3 Inc Mix - Temp transmitter Type: Rosemount 644 HAI1XAJ6M4Q4 S/N: 02539694 6 Inc Mix - Temp transmitter Type: Rosemount PT100 S/N: 03077080 (01989788) 6 Inc / Test unit C
Compressor	- Filter Type: Kaeser FFG-28 B S/N:1405 - Filter Type: Kaeser 3034 S/N:9565 - Filter Type: Kaeser 3034 S/N:10185 - Drain separator Type: Kaeser Aquamat CF38 S/N:3087 - Filter Type: Kaeser FG28 S/N:N/A - Kaeser - 4-year Maint. Agreement Standard Pluss of 18.12.2015 - Compressor Type: Kaeser ASK 32 T S/N:1033 - Compressor Type: Kaeser ESD 352 Sigma S/N:1206 - Condensate trap Type: Kaeser Eco - Drain 30 S/N:12962793 - Condensate trap Type: Kaeser Eco - Drain 14 S/N:12483427 - Condensate trap Type: Kaeser Eco - Drain 14 S/N:12543997 - Condensate trap Type: Kaeser Eco - Drain 14 S/N:12544018 - Condensate trap Type: Kaeser Eco - Drain 31 S/N:12487276 - Condensate trap Type: Kaeser Eco - Drain 31 S/N:12486933 - Dryer Type: Kaeser TF 230 S/N:1071

Figure 34: List of the flow loop equipment

As seen in appendix C, an evaluation study has been performed in order to determine the impact each instrument has on the availability, performance and quality of the flow loop. The Norsok standard has been partially used in this methodology, for example, if the instrument has a redundancy then the impact of it was not considered high on the flow loop availability. The rating data were collected after several meetings with the operator and manufacturing engineer and the manufacturing manager, who are experts in the flow loop. After giving the rating, we classified the equipment into four categories.

These four categories are part of the risk matrix: critical, serious, natural and minor. All the equipment that rated 5 were critical, all equipment rated 4 were considered serious, all the equipment rated 3 were neutral and all the equipment rated 1 and 2 were considered minor.



Category	Number of instruments
Critical	22
Serious	13
Neutral	19
Minor	4

Figure 35: Pie chart and table of the critical, serious, neutral and minor

From Figure 35, it is obvious that 60% of the equipment is considered critical and serious. This equipment should be a priority when we design the preventative maintenance and the autonomous maintenance.

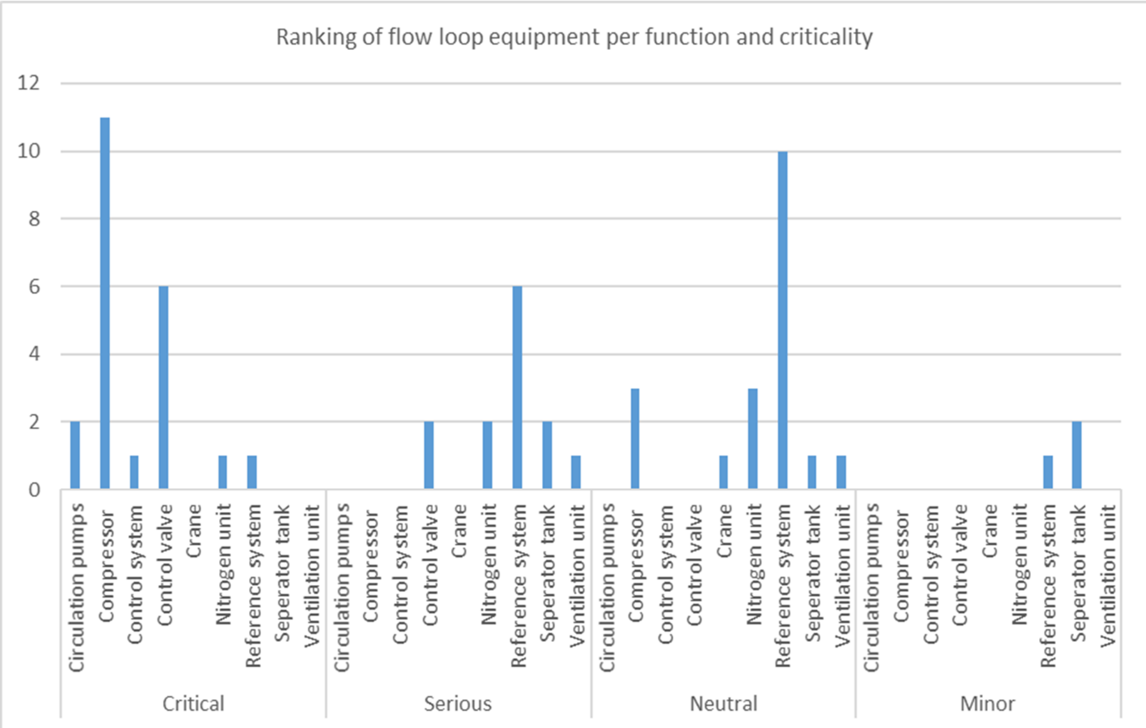


Figure 36: Ranking of equipment per main functions and criticality level

Figure 36 illustrates the equipment of the flow loop in which there are four main categories: critical, serious, neutral and minor. In each category I included the main functions, nitrogen unit, crane, separator tank, control valves, control system, reference system and the flow loop compressor. The main purpose from this visualisation is to give an overview of the number of critical, serious, neutral and minor equipment in each function of the flow loop. This overview provides a holistic picture, based on it, some prioritised decisions can be taken with confidence when implementing the TPM programme. Moreover, this tool is good groundwork in designing the planning phase cycles of the adaptive project management methodology that is suggested to be used during the implementation of the TPM.

A detailed list of the rating of each equipment is given in appendix C. The same classification was used when we listed all the equipment. The top list is all the critical equipment, the second is the serious equipment, the third is the neutral and the last is the minor.

In figure 36 it is clear that the compressor , circulations pump and reference systems are very critical equipment in the flow loop. Therefore, it is highly recommended to prioritize the maintenance systems evaluation for these main functions

8.4.2 Equipment failure probability

There are two approaches to determine failure probability; one is to contact the suppliers (OEM) and the second is to evaluate the failure probability based on historical operational experience.

The analysis of the historical failure record is an interesting exercise which can reveal very beneficial information. This information can be correlated with the OEM/supplier inputs. The correlation analysis study will lead to better decisions during the selection of maintenance system.

The contribution of the OEM and/or the supplier of the equipment in needed in order to determine the equipment failure probability. It is recommended to work with the suppliers of all equipment in the serious and critical equipment in order to determine the failure probability of these equipment. The supplier is expected to provide a transparent proposal for the best possible maintenance approaches for this equipment, one which aims to mitigate or avoid the failure probability. The proposal should demonstrate the expected improvement, risks and associated cost.

The control system of the three-flow loop has an attractive feature, which is the possibility to record faults and alarms. In this thesis, the fault and alarm record have been retrieved and quick quantified analyses performed for the number of occurred faults, as shown in the figure 37

In figure 37 FIT, which is a Coriolis meter, has significant failure rate, which is a very interesting output and needs to be analysed. A root cause analysis using, for example, the 5 whys technique, is highly recommended. The analysis will identify the possible fault causes which might be process-related, design-related or other things.

Based on these statistics, the Coriolis meter will be in square number 8 in figure 33 risk matrix, because it is serious equipment and has relatively high failure rate.

Name	*Occurrence frequency*	*Start*	*Stop*
FIT-1022	75	March 2016	July 2016
FIT-1024	74	March 2016	July 2016
FIT-2001	72	March 2016	July 2016
FIT-2005	73	March 2016	July 2016
FIT-3001	74	March 2016	July 2016
FIT-3005	74	March 2016	July 2016
PB-02		April 2016	May 2016
XX-8001	3	April 2016	December 2016
XX-8003	3	April 2016	December 2016
XY-1034	3	April 2016	December 2016
XY3013	4	March 2016	December 2016
XY3014	5	April 2016	December 2016
XY3015	3	May 2016	December 2016
XY3016	5	March 2016	December 2016
XY3017	5	March 2016	December 2016

Figure 37: Three phase flow loop fault record

9 Proposed implementation plan.

This chapter illustrates the proposed implementation plan for the TPM on Emerson /Roxar three phase flow loop. Prior the development of the high level plan, it was essential to answer some questions in order develop a reliable and robust plan. These questions were how to develop high-level plan which reveal mission, vision and key deliverables of the TPM; should we develop this plan using top down approach or bottom up approach; what can go wrong during the implementation; and finally, what is the most suited project management model and the execution phases for the TPM implementation. The next subchapters provide answers for these questions

9.1 Developing high-level implementation plan

Productivity Inc. developed a form of 10 questions which enables companies to develop the high-level implementation plan. This form used the bottom up approach meaning that form start to formulate implementation key deliverables first and based on these key deliverables, companies can develop the appropriate vision and mission of the TPM. This form covers the following points, but not only limited to these points:

Autonomous Maintenance: TPM implementers need to think of how to organise teams to perform autonomous maintenance, taking into consideration the current organizational structure and equipment requirements.

OEE calculation: The TPM implementers should make a simple and robust system to measure OEE performance. This needs to be compatible with the manufacturing process nature

Communicate TPM vision: TPM implementers need to think of how to communicate the TPM vision because the implementation will only be effective by sharing the vision and understanding the TPM process.

Envision the role of changes: TPM implementers need to think about the role changes in managers, engineering, maintenance and the operators after the implementation of TPM.

9.2 Factors affecting TPM

According to Bamber, Sharp and Hides (1999), the factors affecting successful implementation of TPM are: (1) the setup of the existing organization (2) measures of performance (3) alignment with the company mission (4) the involvement of people; (5) an implementation plan; (6) knowledge and beliefs; (7) time allocation for implementation; (8) management commitment; (9) the motivation of management and workforce.

It is not enough to evaluate these factors once; they need to be evaluated form to time because the implementation process is long process and the status of these factors is dynamic and can be changed.

9.3 Suggested project management model

The adaptive models fit better the projects with a higher level of uncertainty and complexity. As indicated in figure 38, the Adaptive PMLC model consists of several phases that are repeated in cycles, with a feedback loop after each cycle. Planning is done just in time. No effort is wasted on planning the future. The future is unknown and any effort at planning that future will be viewed as non-value-added work (Wysocki, 2009).

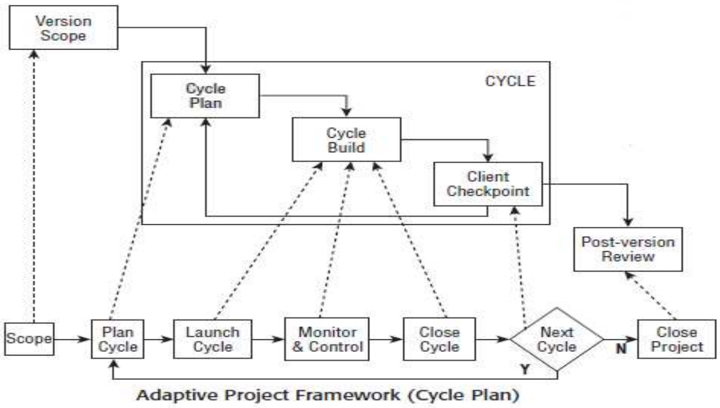


Figure 38: Adaptive Project Cycle Plan

The adaptive project management cycle is very similar to the PDCA (plan-do-check-act) approach, which is a repetitive four-stage system aiming for continuous improvement (CI) in general for the business process management and, particularly, in the programme implementation.

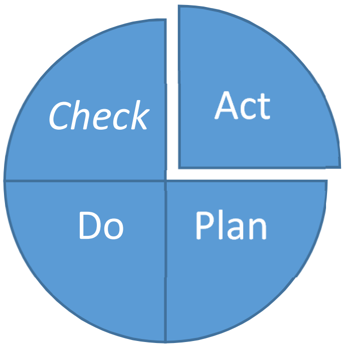


Figure 39: Adaptive Project Cycle Plan

The relation between Figure 38 and Figure 39 is as follows. The plan quadrant is the plan cycle, while the do quadrant contains the launch, monitoring and control and close phases of each cycle. The check quadrant is the next cycle, where the review of the cycle is evaluated. The act quadrant is either to complete the full implementation of the TPM or start a new cycle of the implementation.

9.4 Suggested execution phases

As per figure 40, the recommended implementation processes consist of seven phases. Each phase is described in the following section. Each of these phases should have an evaluation process at the end of the phase, if the phase passes the evaluation criteria, then it can move to the next phase.

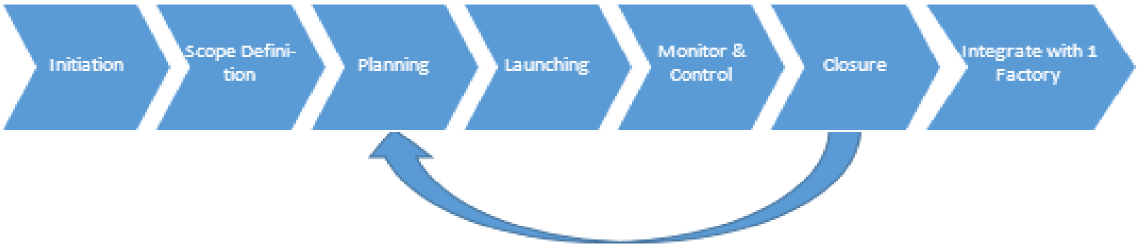


Figure 40: Execution phases

9.4.1 Phase I – Initiation

The TPM concept has been already kicked off in Emerson's factories and the flow loop has been defined as a critical equipment. Therefore, Emerson has already established a TPM Steering Committee and appointed TPM champions. In this phase, the TPM manager should assess the following factors affecting successful implementation of TPM developed from the theory. According to Bamber, Sharp and Hides (1999), these factors are: (1) the existing organisation; (2) measures of performance; (3) alignment with the company mission; (4) the involvement of people; (5) an implementation plan; (6) knowledge and beliefs; (7) time allocation for implementation; (8) management commitment; (9) the motivation of management and workforce. Note: these factors are crucial and they need to be revisited from time to time because the full implementation of the TPM is a relatively long process and takes approximately three to five years and, in this period, the status of these factors can be changed. Consequently, it very important to re-evaluate these factors before the start of each cycle of the TPM implementation.

9.4.2 Phase II- Scoping

In the scoping phase, we define the improvement opportunities. According to Ahuja and Khamba (2008), we can define these opportunities by evaluating the equipment and management systems, define the baseline of critical equipment, define the current OEE, determine equipment condition and determine current maintenance performed on the equipment.

9.4.3 Phase III planning

In this phase, a full review of what should be accomplished in each of the TPM eight pillars must be considered. Clearly, the dependence and interrelation between each pillar should be considered.

Moreover, at this phase measures of performance should be done as well as develop plans for the planned and autonomous maintenance and develop inspection procedures for each equipment.

9.4.4 Phase IV lunch
Implementation of the TPM Plan. Project management techniques should be used

9.4.5 Phase V monitor and control
In this phase, the target is to assess the operations and maintenance personnel's experiences during and post the implementation of the process and also to follow up the progress of the implementation. This will help in conducting the Gap Analysis which is needed to assess what is achieved versus what was planned. The outcome of this phase is to update the lesson learned record with losses and how to reduce them.

9.4.6 Phase VI cycle closure
In this phase, one of two decisions should be taken. Either to start a new adaptive cycle or close the TPM implementation programme and move the integration phase with them to another system. It is pragmatic to review the success factors mentioned in the initiation section at this phase because they are critical for the success of the next cycle

9.4.7 Phase VII Integrate
Integrate with one factory according to Emerson procedures

9.5 Expected number of cycles to fully implement TPM
One cycle of the implementation is completed throughout the thesis. I think two more cycles are still needed in order to fully implement a TPM model that meets the maintenance requirements of the flow loop. The second cycle should aim to implement some of the recommendations of this thesis. As per the agile methodology, time should not be spent to plan the third and last cycle. The plans of the last cycle will be defined during the execution of the second cycle.

10 Recommendations

The recommendations chapter is divided into three subchapters. The first subchapter illustrates the organizational and process recommendations while the second subchapter illustrates the training recommendations and finally, the last subchapter illustrates the quality enhancement recommendations.

10.1 Organizational and processes recommendations

1. Driving a strategic initiative such as implementing the TPM required a dedicated team in order to drive it through the organisation and make it happens. Therefore, it is recommended to create a cross-functional team that consists of a project manager, manufacture engineer, and loop operator and this team should report with a dotted line to the operation director. The project manager role in the entire implementation process is a key role because he will be responsible for the follow-up of the day to day activities and he will be responsible for the communication up and down within the different organisation layers.

   It is expected that Emerson/Roxar will achieve a very high improvement magnitude in the TPM implementation in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be a short time.

2. The TPM requires the involvement of many employee in the organization and thus it is recommended to schedule a quarterly review meeting with all involved stakeholders in order to review the progress and obstacles of the TPM implementation. During this meeting, the team will review present and future cost and benefits of implementing the TPM.

   It is expected that Emerson/Roxar will achieve a very high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be a short time.

3. It is recommended to develop a physical dashboard which illustrates the progress of the TPM implementation programme. In this dashboard, it is also recommended to dedicate a section for the key equipment pictures when it was in new state. This enable the operator to visually correlates between the current and new equipment conditions. This recommendation will improve the autonomous maintenance activities such as the 5S.

   It is expected that Emerson/Roxar will achieve a high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be an average time.

10.2 Training recommendations

4. A high reliable organization should invest in developing the skills of the employee and the skills development can be achieved with training. The training development should not be limited to the training on new equipment, but it should include other training such training on the collective mindfulness and cross-functional training.

   Note: The cross-functional training is very beneficial because it will avoid and /or mitigate the risk of production stoppages. Moreover, with the cross-functional training, Roxar can recover fast in case of employees absence or illness, injury, or other situation which are not avoidable.

   It is expected that Emerson/Roxar will achieve a very high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be a very long time.

5. It is recommended to continue the ongoing training for second flow loop operator which may be a good investment if the Roxar decided to operate the loop for two shifts. Moreover, this suggestion will enable Roxar to execute parallel activities such as writing the report while the other operator runs the loop. As indicated in the discussion section the operator stops the flow loop for 30 minutes daily in order to write the report.

   It is expected that Emerson/Roxar will achieve a very high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be a very long time.

6. It is recommended to train the operators to take necessary maintenance activities such as cleaning and tightening of screws and connections. Because of the current organization structure, this training should not be limited to the flow loop operators it should include team members of another department.

   It is expected that Emerson/Roxar will achieve a high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be an average time.

7. With regards the compressor, Roxar already has a preventative maintenance agreement in place with the supplier. Therefore, the compressor supplier personnel perform the preventative maintenance on the compressor annually. However, it is recommended to negotiate with the compressor supplier if some of the preventative maintenance activities can be carried out by Roxar personnel. If this recommendation is practically possible, it will reduce the preventative maintenance cost as well as it will add flexibility to maintenance scheduling because the preventative maintenance can be easily scheduled during the unplanned production time.

   It is expected that Emerson/Roxar will achieve a high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be an average time.

8. The flow loop piping system requires some maintenance, especially the water piping systems because of the potential corrosion. It is recommended on annually base to perform the following for the exterior surface of pipe and fittings: visually inspect all threaded, welded, and flanged fittings, checking for any leaks or corrosion. Replace or tighten fittings or pipe as required. Remove corrosion by acceptable and suitable method. Bureau of Reclamation (June 2009).

   It is expected that Emerson/Roxar will achieve a high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be a short time.

9. At this stage I would not recommend preventative maintenance for the piping because it is very costly maintenance strategy. As preventative maintenance may require to partially disassemble piping which may alter the system integrity and fixing the system integrity require a lot of extensive testing such as the pressure testing. Also, the preventative maintenance may require to utilize an expensive a nondestructive test method to determine condition of interior surfaces Bureau of Reclamation (June 2009). At this stage, it is not feasible what Emerson/ Roxar expected gained benefits are with preventative maintenance of the piping.

   It is expected that Emerson/Roxar will achieve a low improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be a very long time.

10.3 Quality enhancement recommendations.

10. In general, the decisions and actions should always be based on factual approach and it should be supported with data and quantifications analysis. Based on this, it is recommended to continue capturing and visualizing the OEE and the seven big losses in order to determine potential improvement opportunities and take necessary actions which definitely will aim to enhance the availability and prevent the degradation of equipment.

    It is expected that Emerson/Roxar will achieve a very high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be short time.

11. Despite only four weeks of the OEE were collected but it revealed that the installation and uninstallation process of the MPFM is a long process. Therefore, it is recommended monitor this loss for some time and held few brainstorming sessions in order to make the process leaner and to determine how to reduce the installation and the uninstallation loss. As an example, developing a simple checklist for the installation and the uninstallation of the MPFM may make this task more systematic and it may reduce installation and the uninstallation time.

    It is expected that Emerson/Roxar will achieve a very high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be short time.

12. The quantitative analysis ranked flow loop equipment into four categories critical, serious, neutral and minors with respect to the equipment impact on the overall functionality of the flow loop. It is recommended to prioritize maintenance system development for the critical and serious equipment. Consequently, Emerson/Roxar shall contact the suppliers of critical and serious equipment and get their recommendations for preventative maintenance, autonomous maintenance and the training package.

    It is expected that Emerson/Roxar will achieve a high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be an average time.

13. Some of Roxar personnel in other department are well trained on the refence system of the flow loop. It is recommended to check if these personnel can perform the preventative maintenance activities such as calibration and verifications of the pressure, temperature and coriolis meter. This action will reduce the cost of maintenance as well as it gives flexibility because the preventative maintenance can be scheduled during the planned stop time.

    It is expected that Emerson/Roxar will achieve a high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be a short time.

14. It is recommended to perform the calibration and verification of the instrument in the unplanned operating time in order to enhance the OEE.

    It is expected that Emerson/Roxar will achieve a high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be a short time.

15. A strict procedure needs to be developed when collecting the data which means that everything that makes sense should be included. Therefore, it is recommended to develop a process for gathering, analyzing and reviewing the quality of the data of the existing systems such as 5S and the OEE. This process should include three personnel initiator, checker, and reviewer.

    It is expected that Emerson/Roxar will achieve a high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be a short time.

16. It is recommended to perform cost analysis to determine the breakeven point at which the flow loop operating hour cost will be minimized and the OEE is maximized.

    It is expected that Emerson/Roxar will achieve an average improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be a long time.

17. Roxar has made a list for many of the flow loop equipment and instruments, but this list does not include all existing equipment and instruments and it is recommended to modify this list and make it inclusive for all flow loop equipment and instruments.

    It is expected that Emerson/Roxar will achieve a high improvement magnitude in the TPM implementation programme in the case of implementing this recommendation. Moreover, the time required to implement this recommendation is expected to be an average time.

10.4 Recommendations prioritization matrix

The prioritization of recommendations was made based on the following two perspectives: The expected improvement and the required time to implement these recommendations. The expected improvement perspective has 5 categories very high, high, average, low and very low. The required time to implement the recommendations has 5 categories very short, short, average, long and very long.

The prioritization weighting criteria are subjective and based on the writer experience. Therefore, prioritization matrix is debatable.

Required time

		Very short	Short	Average	Long	Very long
Expected improvement	Very high		1,2,10,11		5	4
	High		8,13,14,15	3,6,7,12,17		
	Average				16	
	Low					9
	Very low					

Figure 41: Recommendations prioritization matrix

Based on the above matrix it is recommended to prioritize recommendations as per the following sequences 1,2,10,11,8,13,14,15,3,6,7,12,17,5,4,16 and 9.

11 Conclusion

This chapter summarizes the thesis achievements and correlates between these achievements and the thesis objectives.
Having a system that gathers and visualises the OEE and seven big losses in hands, means that the first objective of this thesis was achieved. This OEE system needs further development because it was developed only for one type of flow test. Since Roxar runs various types of flow tests, the system should be modified to accommodate all flow test types.

The second objective of this thesis was creating a criticality analysis in order to rank the flow loop equipment with respect to their impact on the availability, performance, and quality of the flow loop. This objective also achieved, because a list of the equipment that has a critical, serious, neutral and minor impacts on the flow loop functionality was made and it is available in appendix C. Furthermore, this quantitative analysis revealed the number of critical, serious, neutral and minor equipment per each main functions of the flow loop.

The third objective of this thesis was achieved as well, becosue a life cycle cost calculation methodology was developed in accordance to the norsok standard specifications. This methodology calculated the life cycle cost for two pumps from two different suppliers as illustrated in appendix D. This exercise proved that the selection criteria should be in accordance to the total expected life cycle cost not the capital cost. In this exercise, despite supplier A pump has lower capital cost than the supplier B pump, but the overall cost of supplier A pump is larger than supplier B pump in 10 years operating time. That is because the energy consumption of supplier A is little bite higher than supplier B.

Chapter 9 of this thesis illustrates tool or form which leads TPM implementers to develop a high-level TPM implementation plan. Furthermore, the study of the TPM literature showed that there is no one TPM programme fits all applications because the TPM is expandable. Based on this, it was concluded that the TPM solution that fits Emerson/Roxar current organizational setup and flow loop maintenance requirements is fuzzy. Therefore, the agile methodology was suggested for the TPM implementation programme. Finally, it can be concluded that the last and fourth objective of the thesis was achieved.

Conclusion summary

This thesis contributed with positive progress in the following TPM pillars: maintenance improvement; autonomous maintenance; focused improvement progress; early equipment management maintenance; maintenance improvement; training and the office TPM.

12 References

Benjamin S. Blanchard, (1997) 'An enhanced approach for implementing total productive maintenance in the manufacturing environment', *Journal of Quality in Maintenance Engineering,* 3(2), pp. 69-80.

C.J. Bamber,J.M. Sharp,M.T. Hides (1999) 'Factors affecting successful implementation of total productive maintenance: A UK manufacturing case study perspective', *Journal of Quality in Maintenance Engineering,* 5(3), pp. 162-181.

Pradeep Kumar Shetty , Lewlyn L. R. Rodrigues (September 2010) 'Total Productive Maintenance of a Diesel power generating unit of a institution campus', *International Conference on Mechanical and Electrical Technology,*

Bupe. G, Mwanza, Charles Mbohwa. (23 December 2015) 'Design of a Total Productive Maintenance Model for Effective Implementation', *Procedia Manufacturing,* 4(), pp. 461-470 [Online]. Available at: *http://www.sciencedirect.com/science/article/pii/S2351978915011798* (Accessed: March 2017).

Direct Recruiters Inc () *Importance of Cross Training in the Workplace,* Available at: *http://www.directrecruiters.com/uncategorized/blog/importance-of-cross-training-in-the-workplace/* (Accessed: May 2017).

F.T.S. Chana,*, H.C.W. Laub , R.W.L. Ipc , H.K. Chana , S. Konga (9 October 2003) 'Implementation of total productive maintenance', *International journal of production economics,* (), pp. 71-94 [Online]. Available at: *www.sciencedirect.com* (Accessed: March 2017).

I.P.S. Ahuja and J.S. Khamba (2008) 'Total productive maintenance: literature review and directions', *International Journal of Quality & Reliability Management,*

Jonas Bergsman, Anders Hall, Johan Johansson, Andreas Jaensson/ linkopings universitet (2010) *Improving maintenance efficiency at AstraZeneca through increased use of TPM*, https://pdfs.semanticscholar.org/4fde/12da1991c132a9eb2452dc75a11b92df82a8.pdf?_ga=2.43790182.256393092.1496432133-1117551142.1496432133: linkopings universitet.

linkedin (June 10, 2014) *Top 5 OEE Mistakes,* Available at: *https://www.linkedin.com/pulse/20140610131501-8550980-top-5-oee-mistakes* (Accessed: March 2017).

Marcelo Rodrigues , Kazuo Hatakeyama (2006) 'Analysis of the fall of TPM in companies', *Journal of Materials Processing Technology,* (179), pp. 276-279.

Marius Vileiniskis, , Rasa Remenyte-Prescott , Dovile Rama , John Andrews (May 2016) 'Fault detection and diagnostics of a three-phase separator', *Journal of Loss Prevention in the Process Industries,* Volume 41(), pp. 215-230.

Mauric Brien (May, 2015) *TPM and OEE.* [Online]. Available at: *https://www.shannonchamber.ie/wp-content/uploads/2015/11/OEE-mini-booklet-revision-01.pdf* (Accessed: April 2017).

Ottosson, Daniel/Lule University of Technology, LTU (2009) *The initiation of Total Productive Maintenance to a pilot production line in the German automobile industry,* http://ltu.diva-portal.org/smash/get/diva2:1027826/FULLTEXT01.pdf: Lule University of Technology, LTU.

PRODUCTIVITY INC. () *TEN FRAMING QUESTIONS FOR TPM IMPLEMENTATION,* Available at: *www.productivityinc.com/* (Accessed: March 2017).

PRODUCTIVITY INC. () *TPM CONSULTING,* Available at: *www.productivityinc.com/* (Accessed: March 2017).

PRODUCTIVITY INC. () *TPM EQUIPMENT SCAN,* Available at: *www.productivityinc.com/* (Accessed: March 2017).

PRODUCTIVITY INC. () *TPM PROGRESS SCAN,* Available at: *www.productivityinc.com/* (Accessed: March 2017).

PRODUCTIVITY INC. () *TPM PROGRESS SCAN,* Available at: *www.productivityinc.com/* (Accessed: March 2017).

R. Keith Mobley (2008) *MAINTENANCE ENGINEERING HANDBOOK*, Seventh Edition edn., USA: The McGraw-Hill Companies, Inc.

Robert K. Wysocki (2009) *Effective Project Management: Traditional, Agile, Extreme, Fifth Edition*, Fifth edn., Canada: Wiley Publishing, Inc..
Society for Maintenance & Reliability Professionals () *Introduction: TPM,* Available at: *https://smrp.org/* (Accessed: March 2017).

The Right Staff () *Six Benefits of Cross-Training Employees,* Available at: *http://www.therightstaff.com/2015/02/20/six-benefits-of-cross-training-employees* (Accessed: May 2017).

Vorne Industries Inc () *The Eight Pillars,* Available at: *http://www.leanproduction.com/index.html* (Accessed: May 2017).

Saybrook University () Mindfulness and The Bottom Line: Five Benefits of Mindful Leadership, Available at: https://www.saybrook.edu/rethinkingcomplexity/rc-posts/mindfulness-and-bottom-line-five-benefits-mindful-leadership/ (Accessed: June 2017).

Heartwood Refuge Retreat Center () Benefits of Mindfulness, Available at: https://www.heartwoodrefuge.org/benefits-of-mindfulness (Accessed: June 2017).

Zahid Habib,Kang Wang/ Royal Institute of Technology Sweden (March, 2008) *Implementation of Total Productive Maintenance on Haldex Assembly Line*

NORSOK STANDARD (2001) 'Criticality analysis for maintenance purposes', in (ed.) Z-008. Norway: Norwegian Technology Centre,

Wikipedia (NA) 5S (methodology), Available at: https://en.wikipedia.org/wiki/5S_(methodology) (Accessed: May 2017).

Terje Aven (2011) Quantitative Risk Assessment, Norway: Universitet i Stavanger, Norway.

3182641-PAS-FS-F1 the functional specification Roxar Flow Measurement

Bureau of Reclamation (June 2009) Maintenance Scheduling for Mechanical Equipment , Denver, Colorado: .

Appendix A - Form used in evaluating TPM initiative on the flow loop

PRODUCTIVITY

Productivity Inc.
375 Bridgeport Avenue, 3rd Floor
Shelton, CT 06484
203-225-0451
www.productivityinc.com

AN OPERATIONAL EXCELLENCE PROGRESS SCAN

HOW WELL ARE YOUR TPM INITIATIVES DOING?

FIND OUT →

PRODUCTIVITY

Implementation the TPM on the three-phase closed flow loop.

Complete the Scan by ranking your progress from level 1 to level 5 in each of the categories. The scan defines the level 1 and level 5 baselines.

PROCESS/TECHNICAL*

Category	Level 1 (lowest)	Ranking	Level 5 (highest)
Maintenance Improvement	90% of maintenance is reactive	1 2 3 4 5	90% of maintenance is proactive
Autonomous Maintenance	Operators "run" equipment; maintenance "fixes it"	1 2 3 4 5	Operators own the process—the 7 steps of Autonomous Maintenance are in place
Focused Improvement	No OEE data collected	1 2 3 4 5	85% OEE and Zero Losses reported on critical assets; OEE collected on all assets
Safety	Numerous safety incidents occur annually	1 2 3 4 5	Safety incident rate is benchmark for your industry
Training and Skill Development	No training matrix in place for operators and maintenance personnel; less than 10hrs/year for skill enhancement	1 2 3 4 5	Training matrix in place; 90hrs/year for skill enhancement
Quality Maintenance	Quality issues are addressed by Quality Assurance Dept.	1 2 3 4 5	Sigma level and higher consistently reported (when incidents occur they are handled at the source)
Early Equipment Management/Maintenance Prevention Design	No life cycle cost data being collected	1 2 3 4 5	Life cycle cost (and cross functional teams) used to design/acquire new equipment
Office TPM	No involvement by Administrative departments in the day-to-day equipment improvement	1 2 3 4 5	Admin departments participate in TPM activities

______ 40 Maximum Points

STRATEGIC/SOCIAL*

Category	Level 1 (lowest)	Ranking	Level 5 (highest)
Key Strategic Objectives	Not defined	1 2 3 4 5	Focused/Deployed
Standard Work/Adherence	Not practiced	1 2 3 4 5	All encompassing—Ideal Standards
Leadership Development	No formal approach	1 2 3 4 5	Leaders as Teachers
On-going process improvement training	Little, if any	1 2 3 4 5	Formalized approach
Continuous Improvement focus	No formal approach	1 2 3 4 5	Enterprise Wide
Multi-Skill/Multi-Craft	Limited	1 2 3 4 5	Total Flexibility
Improvement Results	Not Sustained	1 2 3 4 5	Implemented across shifts, lines, facilities
The decision making process	Hierarchical	1 2 3 4 5	Diffused/quick/good decisions

______ 40 Maximum Points

Total ______ **80 Maximum Points**

If your score is:

60-79 congratulations, you're doing a great job

59-40 you're on the right path, but there is room for improvement

39 or less, significant improvement opportunity exists

* Not all-inclusive

Note: The intent of this Scan is to provide a macro look at available improvement opportunities. Absent a score of 80 points, there is room for improvement!

PRODUCTIVITY
Productivity Inc.
375 Bridgeport Avenue, 3rd Floor
Shelton, CT 06484
203-225-0451
www.productivityinc.com

Appendix B Form used in evaluating the flow loop equipment status

TPM Scan

PRODUCTIVITY

Date ____________ Plant Flow loop

Team ____________ Line/Equipment ____________

TANK

System	Part	Score 1-4	Score 5-8	Score 9-10	Pts
(1) Main Body	Overall condition	Dirty	Clean	Cleaned & painted	7
	Anchor bolts	Loose or missing	Properly torqued	Registration marks Used	6
	Machine screws & bolts	Loose or missing	Properly torqued	Registration marks used	6
	Auxiliary equipment	Obsolete systems present	Obsolete frames, brackets, etc.	No unnecessary parts	9
(2) Electrical Systems	Panels and boxes	Dirty, loose, opened, blocked, dirty filters	Clean, painted, fastened	Wires well organized, labeled, proper air flow	6
	Wires	Wires hanging loose or worn	Wires not well organized	Wires clean, marked, organized	5
	Motors	Dirty	Clean	Clean and visually controlled	7
	Counters	Not working	Work sometimes	Count properly	NA
	Indicator lights	Smashed and/or obsolete	Do not light	All work properly	9
	Temperature controllers/ switches	Not working	Only work sometimes	Always work properly	7
(3) Pneumatic Systems	Main air lines	Leak air or have obsolete lines	Color coded, no obsolete lines	Air direction identified	9
	Air gauges	Broken and/or obsolete	Work, but are not visible	Marked at proper setting & visible	8
	Filters	Dirty or difficult to access	Clean, but difficult to change	Clean & easy to change	5
	Air hoses	Worn and leaking	Not well organized	Clean and well organized	8
	Air blowers	Dirty	Clean & properly filtered	Entire blower system clean	NA
	Pneumatic cylinders	Dirty, not working properly, leak	Clean, but often fail	Clean & work properly	NA
	Pneumatic lubricators	Leak, over/under lubricated	Properly filled	Work properly, color coded for proper level	NA
	FRL's	Not maintained	Maintained but not accessible	Maintained, accessible, color coded	NA
	Solenoids	Dirty, not working, or obsolete	Operating properly, not obsolete	Clean, properly labeled	9

System	Part	Score 1-4	Score 5-8	Score 9-10	Pts
(4) Lube Systems	Pump? Grease fittings	Dirty or painted over, hard to access	Color coded but hard to access	Easy to access/ color coded/ manifolds	9
	Oil cups	Leak	No leaks	Color coded & labeled	NA
	Oil reservoir	Hard to access, leaking	Easy to access & read oil level	Sight glasses level marked, type of oil marked	NA
	Oil pumps/misters	Leak, over/under lubricated	Properly filled	Work properly and color coded	NA
	Grease & oil lines	Some not connected	All connected, some leak	No leaking lines	NA
(5) Drive Systems	Gears	Broken teeth, excessive play	Worn teeth, slight play	No wear, no play, proper lubrication	NA
	Pulleys/sprockets	Loose or worn	No play	Not worn, properly lubricated	NA
	Drive belts	Cracked, worn, loose	Good condition	Properly tightened, visual access /control	9
	Drive shafts	Scored, wobbly, play in bearings	No visible damage	Completely clean, properly lubricated	9
	Drive chains	Worn	Loose	Not worn, properly tightened, lubricated	NA
	Guards	Hide drive system	Labeled with dir. & belt/chain info	See-through and easy to remove	4
	Bearings/bushings	Improperly lubed; worn bearings	Properly lubed, some play, noise	Properly lubed, no play, no noise	9
(6) Hydraulics	Filters	Dirty	Clean	Easy access, color coded	NA
	Tank	Dirty	Clean	Color coded	NA
	Cylinders	Dirty or leaking	Look good	No leaks, color coded	NA
	Lines	Worn, damaged, leaking	No damage/leaks	Properly tightened, color coded	NA
(7) Work Stations and Activity Boards	Overall area	Dirty	Clean	Clean and organized	9
	Tools	Dirty	Not organized	Organized and visually controlled	6
	Quality Measures	Not present	On line but no specific location	On line, designated location	1
	OEE (MTBF, MTTR)	No evidence of OEE	OEE history on line	OEE used and posted by operator	1
	SOP's(OPL'S)	No SOPs on line	SOPs present, but probably unused	SOPs kept in manual and used	
	Provisional Standards (clean, inspect, lube)	Not present	Present, but no evidence of use	Documented use	6
	Pictures	None present	"Before" pictures present	"Before" and "after" pictures present	1
	Abnormality summaries & tags	None present	Present but incomplete	Completely documented	7
	Improvement summaries & tags	None present	Present, but none completed	Complete, documented, improvement bulletins in use	5

[Total points + (10 x number of lines used)] x 100 = _____ %

If you score under 85%, then you have opportunities to make improvements that can increase your capacity and save you money. Contact us to get you started!

Appendix C The ranking of flow loop equipment.

Critical Equipment									
Asset Number	**Asset Description**	**Location**	**Spare parts**	**Impact on availability**	**Impact on performance**	**Impact on quality**	**Criticality**	**Maximum**	**Failure Likelihood**
MAS-CB-01	Filter Type: Kaeser FFG-28 B S/N:1405	Compressor	No	5	5	5	15	5	
MAS-CB-02	Filter Type: Kaeser FE-28 S/N:6991	Nitrogen unit	No	5	5	5	15	5	
MAS-CB-03	Cyclone Type: Kaeser ZK072 S/N:398369360004	Seperator tank	NA	5	5	5	15	5	
MAS-CB-06	Drain separator Type: Kaeser Aquamat CF38 S/N:3087	Compressor	No	5	5	5	15	5	
MAS-CB-07	Filter Type: Kaeser FG28 S/N:N/A	Compressor	No	5	5	5	15	5	
MAS-CERT-010	Delta V Guardian Support agreement Model nr: VE9041S0200	Control system		5	5	5	15	5	
MAS-KA-01	Compressor Type: Kaeser ASK 32 T S/N:1033	Compressor	No	5	5	5	15	5	
MAS-PB-01	Centrifugal pump Type: Grundfos NB80-315/320 E-F-K-BQQ S/N:A98449852P213270003	Circulation pumps	No	5	5	5	15	5	
MAS-PB-02	Centrifugal pump Type: Grundfos NB125-315/338 E-F-K-BQQ S/N:A98449769P213240001	Circulation pumps	No	5	5	5	15	5	
MAS-PB-03	Compressor Type: Kaeser ESD 352 Sigma S/N:1206	Compressor	No	5	5	5	15	5	
MAS-TR-01	Condensate trap Type: Kaeser Eco - Drain 30 S/N:12962793	Compressor	No	5	3	3	11	5	
MAS-TR-06	Condensate trap Type: Kaeser Eco - Drain 14 S/N:12543997	Compressor	No	5	3	3	11	5	
MAS-TR-07	Condensate trap Type: Kaeser Eco - Drain 14 S/N:12544018	Compressor	No	5	3	3	11	5	
MAS-TR-08	Condensate trap Type: Kaeser Eco - Drain 31 S/N:12487276	Compressor	No	5	3	3	11	5	
MAS-TR-09	Condensate trap Type: Kaeser Eco - Drain 31 S/N:12486933	Compressor	No	5	3	3	11	5	
MAS-XX-100	Dryer Type: Kaeser TF 230 S/N:1071	Compressor	No	5	4	5	14	5	
	Actuators valves - gas	Contol valve	No	5	4	5		5	
	Actuators valves - gas	Contol valve	No	5	4	5		5	
	Actuators valves – Disel	Contol valve	No	5	4	5		5	
	Actuators valves – Disel	Contol valve	No	5	4	5		5	

	Actuators valves -water	Contol valve	No	5	4	5		5	
	Actuators valves -water	Contol valve	No	5	4	5		5	

Serious Equipment

Asset Number	Asset Description	Location	Spareparts	Impact on availability	Impact on performance	Impact on quality	Criticality	Maximum	Failure Likelihood
MAS-AT-1030	Gas transmitter Type: MSA PrimaX I S/N:08/13-11566	Seperator tank	No	3	4	1	8	4	
MAS-AT-1031	Gas transmitter Type: MSA PrimaX I S/N:08/13-02662	Seperator tank	No	3	4	1	8	4	
MAS-AT-1032	Gas transmitter Type: MSA PrimaX I S/N:08/13-02140	Nitrogen unit	No	3	4	1	8	4	
MAS-AT-1033	Gas transmitter Type: MSA PrimaX I S/N:a-08/13-02143	Ventilation unit	No	3	4	1	8	4	
MAS-CV-100	Nitrogen Generator Type: Oxymat NITROMAT N350 ECO S/N:N2013072	Nitrogen unit	No	3	4	1	8	4	
MAS-FIT-1022	Coriolis flow meter Type: Micro Motion CMFS050M 313N2FZNKZZ S/N:12093561	Reference system	No	3	4	4	11	4	
MAS-FIT-1024	Coriolis Type: Micro Motion CMFS150M328N2FZNKZZ S/N: 12091878	Reference system	No	3	4	4	11	4	
MAS-FIT-2001	Coriolis Type: Micro Motion CMF300M355N2F6NZZ S/N: 14374988	Reference system	Yes	3	4	4	11	4	
MAS-FIT-2005	Coriolis Type: Micro Motion CMF300M355N2F6NZZZ S/N: 14377776	Reference system	Yes	3	4	4	11	4	
MAS-FIT-3001	Coriolis flow meter Type: Micro Motion CMF400M 451N2F6NZZZ S/N:14373079	Reference system	Yes	3	4	4	11	4	
MAS-FIT-3005	Coriolis flow meter Type: Micro Motion CMF400M 451N2F6NZZZ S/N:14283621	Reference system	Yes	3	4	4	11	4	
	Actuators valves - liq mix	Contol valve	No	3	4	3		4	
	Actuators valves - liq mix	Contol valve	No	3	4	3		4	

Neutral Equipment

Asset Number	Asset Description	Location	Spareparts	Impact on availability	Impact on performance	Impact on quality	Criticality	Maximum	Failure Likelihood
MAS-CB-04	Filter Type: Kaeser 3034 S/N:9565	Compressor	Yes	3	3	3	9	3	
MAS-CB-05	Filter Type: Kaeser 3034 S/N:10185	Compressor	Yes	3	3	3	9	3	
MAS-PT-1036	Pressure transmitter Type: Rosemount 3051 TG3A2B21BI1M5P1Q4Q8 S/N:9452894 Gas Section	Reference system	Yes	2	3	3	8	3	

MAS-PT-2002	Pressure transmitter Type: Rosemount 3051 TG3A2B21BI1M5P1Q4Q8 S/N:9452891 3 Inc Mix	Reference system	Yes	2	3	3	8	3	
MAS-PT-3002	Pressure transmitter Type: Rosemount 3051 TG3A2B21BI1M5P1Q4Q8 S/N:9452892 6 Inc Mix	Reference system	Yes	2	3	3	8	3	
MAS-PT-3011	Pressure transmitter Type: Rosemount 3051 TG3A2B21BI1M5P1Q4Q8 S/N:9568827 3 Inc / Test unit A	Reference system	Yes	2	3	3	8	3	
MAS-PT-3021	Pressure Transmitter Type: Rosemount 3051 S/N: 7303040/0699 Old: RFM-774-135 6 Inc /Test unit C	Reference system	Yes	2	3	3	8	3	
MAS-TR-02	Condensate trap Type: Kaeser Eco - Drain 31 S/N:12600306	Nitrogen unit	No	3	3	3	9	3	
MAS-TR-03	Condensate trap Type: Kaeser Eco - Drain 31 S/N:1260305	Nitrogen unit	No	3	3	3	9	3	
MAS-TR-04	Condensate trap Type: Kaeser Eco - Drain 14 S/N:12483396	Nitrogen unit	No	3	3	3	9	3	
MAS-TR-05	Condensate trap Type: Kaeser Eco - Drain 14 S/N:12483427	Compressor	No	3	3	3	9	3	
MAS-TRSM-002	Pressure Transmitter Type: Rosemount Model 3051 0-10Bar S/N: 9452893 3 Inc / Test unit B	Reference system	Yes	3	3	3	9	3	
MAS-TT-1000	Temp transmitter Type: Rosemount 248 DXI1D2NSWA3WK1B4Q4K1169 S/N:2547964	Ventilation unit	Yes	3	3	3	9	3	
MAS-TT-1001	Temp transmitter Type: Rosemount ??? Same as 62-TT1000 S/N:2547965	Ventilation unit	Yes	3	3	3	9	3	
MAS-TT-1026	Temp transmitter Type: Rosemount 648 DX1D1I1WA3WK1M5Q4XA S/N:2539698 Liquid seperator	Seperator tank	Yes	3	3	3	9	3	
MAS-TT-1036	Temp transmitter Type: Rosemount 644 HAI1XAJ6M4Q4 S/N: 02539695 Gas Section	Reference system	Yes	3	3	3	9	3	
MAS-TT-2003	Temp transmitter Type: Rosemount 644 HAI1XAJ6M4Q4 S/N: 02539696 3 Inc Mix	Reference system	Yes	3	3	3	9	3	
MAS-TT-3003	Temp transmitter Type: Rosemount 644 HAI1XAJ6M4Q4 S/N: 02539694 6 Inc Mix	Reference system	Yes	3	3	3	9	3	
MAS-TT-3019	Temp transmitter Type: Rosemount PT100 S/N: 03077080 (01989788) 6 Inc / Test unit C	Reference system	Yes	3	3	3	9	3	
MAS-LIFT-011	Gantry Crane Type: Demag 2,5 t S/N: 41-1037	Crane	No	2	2	1	5	2	

Minor Equipment									
Asset Number	**Asset Description**	**Location**	**Spareparts**	**Impact on availability**	**Impact on performance**	**Impact on quality**	**Criticality**	**Maximum**	**Failure Likelihood**
MAS-ACTY-001	Mixing of Saltwater in FlowLoop	Seperator tank	NA	1	1	1	3	1	
MAS-PT-1027	Pressure transmitter Type: Rosemount 3051 TG3X2B21PWA3WP5B4I1M5P1Q4Q8 S/N:9452890 Liquid separator	Seperator tank	Yes	1	1	1	3	1	
MAS-TRSM-001	Temp Transmitter Type: Rosemount Pt100 S/N: 02539697 S/N #2: 03395801 Tag: TT3012 3 Inc / Test unit A+B	Reference system	Yes	1	1	1	3	1	

Appendix D. Life cycle calculation

This study has been developed during the operation maintenance course by myself and assistance from one of the team member.

In this small study, we have been performed of the Life cycle cost for pumps which is relevant equipment in the flow loop. We have developed a life cycle cost calculation sheet according to NORSOK Standard. It has been decided to run the life cycle cost for the single stage centrifugal pumps. It has been assumed that s pump will be used for pumping fresh water. This assumption used to simplify the energy consumption calculation of the pump. We have found some difficulties gathering very precise prices from the pumps suppliers globally, due some reasons (competitions, confidential information etc). The equipment and material purchase cost obtained from industrial pump list of the 2011 (internet). These prices increased by 5 %, which represent the summation of the actual inflation rates from 2011 till 2014.

	Hour rate in NOK
Contractor rate	500
Supplier representative A rate	900
Supplier representative B rate	950
Operator rate	700

The man-hours, commissioning and installation cost calculation we have used the below listed rates.

Present Value Method

When calculating the total cost over a time span, it is necessary to combine outlays spread in time in an accurate way. The principal method for this is called the present value method, which compares the value of a cash unit today to the value of that same cash unit in the future, taking inflation and return rates into account. The below formula is used for the present value calculation.

$$\sum_{t=0}^{n} = \frac{S_t}{(1+k)^t}$$

Where:

St = Net cost in year t. This can be assumed equal for all the years, it can vary according to production, or it can have some other given variation throughout the lifetime.

N = The lifetime of the equipment/function to be evaluated. When the required lifetime of the equipment exceeds the expected lifetime, the required life is used.

K = The discount rate/interest rate to be used for the evaluation.

In the underneath table shows the pumps A and B values for the 10 years life time. The discount rate was 6.5% and the inflation rate is 1.5%. So the net discount rate is 5 %.

Year	1	2	3	4	5	6	7	8	9	10
Supplier A NOK	42857,14	40816,33	38872,69	37021,61	35258,68	33579,69	31980,66	30457,77	29007,4	27626,1
Supplier B NOK	44761,9	42630,39	40600,37	38667,02	36825,73	35072,12	33402,02	31811,45	30296,62	28853,92

Sensitivity Analysis

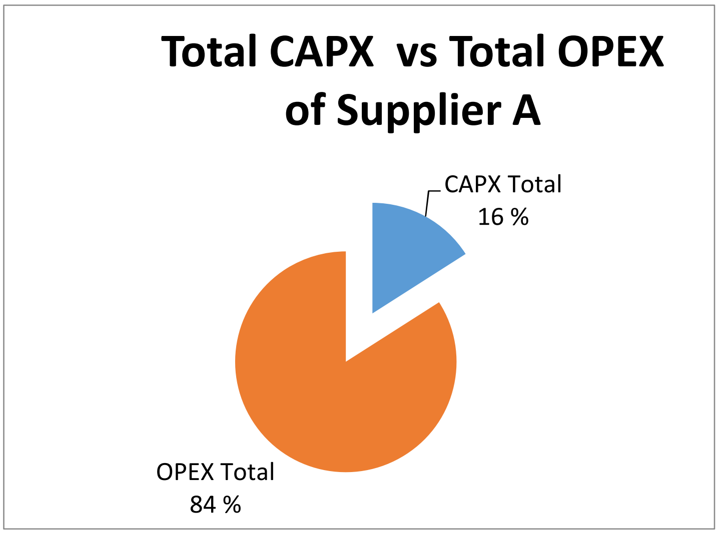
In the life cycle cost calculations, we calculating the expected future cost, where many factors assumed to be fixed. These assumptions made to simplify the initial LCC calculation scenario. These factors same as the inflation rate, interest rate, vendor's rates and KWH tariff are variables. So running several sensitivity analyses is a mandatory, in order to predict many LCC calculations scenarios. The sensitivities analysis normally run by increasing and decease these factors by 40 %. Experts in the related disciplines (commercial, technical) should be used in running and assessing of the LCC scenarios.

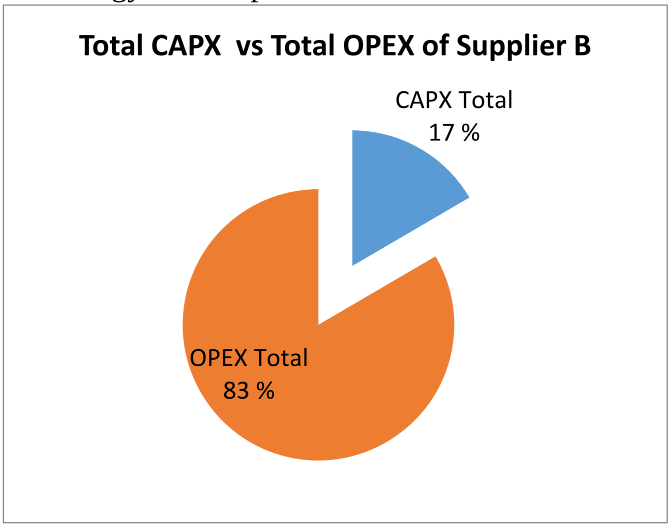
The underneath table demonstrates the overall view of the capital and operating cost of two different pumps.

Life Cycle Cost Summary of Supplier A/B			
		Supplier A NOK	**Supplier B NOK**
CAPITAL COST			
	Equipment and materials purchase cost	45000	47000
	Installation cost	5950	5425
	Commissioning cost	3500	2875
	Insurance spares cost	9000	9400
	Reinvestment cost	56750	56975
CAPX Total (NOK)		120200	121675
OPERATING COST for 10 years			
	Man hour cost	333416,83	327053,4
	Spare Parts Consumption	124615,6	99359,6
	Energy Consumption	124820,74	135929,79
	Logistic support cost	50000	50000
OPEX Total(NOK)		632853,17	612342,79
Total (NOK)		753053,17	734017,79

As shown in the above table the supplier A pump has a cheaper capital cost, but it is more expensive than supplier B pump in 10 years operating time. It is also even going to be more expensive by extending the operation time. So the selection criteria should be according to the total life cycle cost not the capital cost.

In the underneath pie charts illustrates the total Capx and total Opex of the both A and B pumps. It is very clear that the total Opex for both pumps are around 5 times higher than the Capx. This phenomena is not strange for the LCC of the pumps, because it well known that the energy consumption



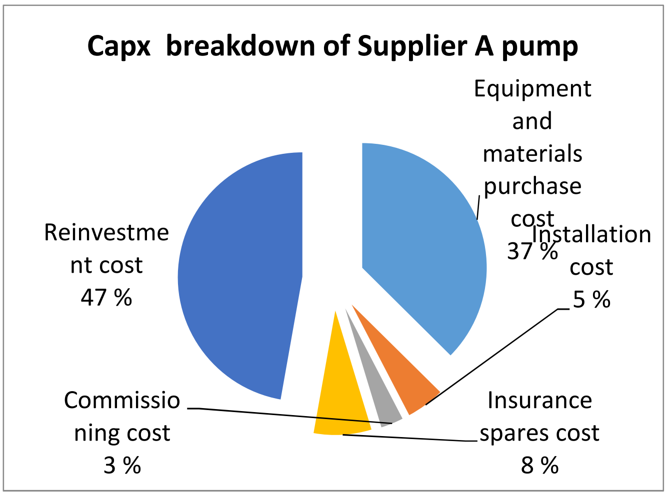


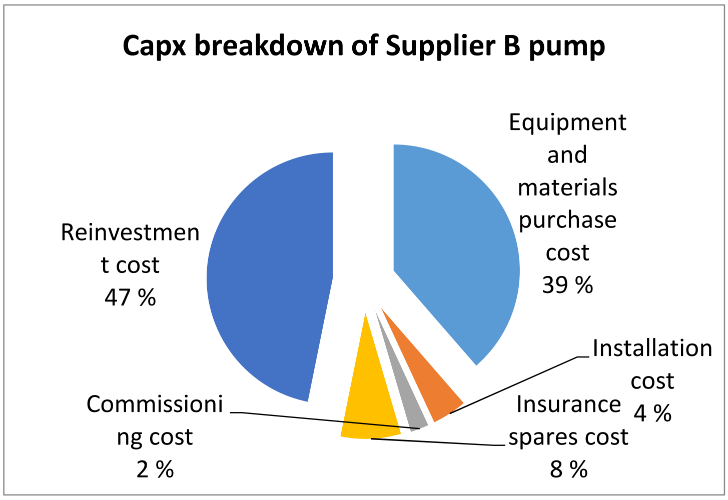
Capital cost: Capital cost shall be calculated by adding the following cost elements:

- Equipment purchase cost.
- Installation cost.
- Commissioning cost.
- Insurance spares cost.
- Reinvestment cost

The underneath table and pie charts illustrate the cost breakdown of both pumps.

	Supplier A NOK	Supplier B NOK
Equipment and materials purchase cost	45000	47000
Installation cost	5950	5425
Commissioning cost	3500	2875
Insurance spares cost	9000	9400
Reinvestment cost	56750	56975





Equipment Cost:

This represents the initial cost of the pumps.

Installation Cost:

Installation cost = (Installation man-hours x Man-hour rate installation)

Reinvestment:

Reinvestment cost = *Removal cost old equipment + Purchase cost new equipment + Installation cost new equipment + Commissioning cost new equipment – equipment value after 10 years.*

Commissioning cost:

Commissioning cost = (Offshore man-hours commissioning contractor x Offshore man-hour rate commissioning contractor) + (Offshore man-hour operator crew x Offshore man-hour rate operator crew) + (Offshore man-hours vendor x Offshore man-hour rate vendor)

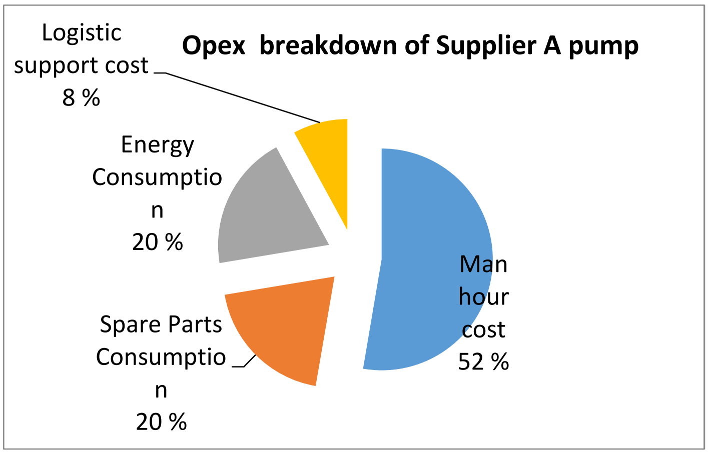
Operation cost:

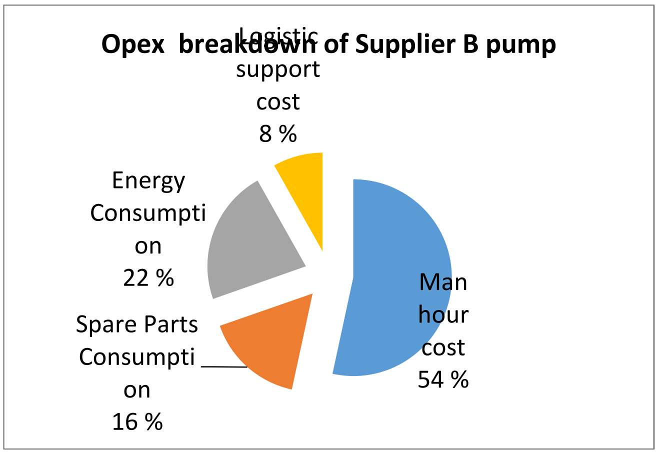
Operating cost should be calculated by adding the following cost elements:

- Man-hour cost.
- Spare parts consumption cost.
- Logistic support cost.
- Energy consumption cost.

The underneath table and pie charts illustrate the summary of the Opex cost for supplier A and B

	Supplier A NOK	Supplier B NOK
Man hour cost (annual)	33341,6832	32705,34
Spare Parts Consumption	12461,56	9935,96
Energy Consumption	12482,07398	13592,97857
Logistic support cost	5000	50000
Total per year	63285,31718	61234,27857





Man-hour cost calculation:

The man-hour calculation is the summation of the corrective maintenance man-hour and preventive maintenance man-hour.

The **corrective maintenance** (man hour) formula is mentioned below

$$CMM = \lambda T \times 8760 \times MTTR \times A \times M$$

Where

CMM = Average annual man-hour cost for corrective maintenance

λT = Total failure rate as number of failures. This includes all failures

8760 = Number of hours in a year

MTTR = Mean Time to repair. The time in hours it takes to repair the faulty item back to operating condition

A = number of men required to do the work. This also includes the safety aspect.

M = man-hour rate.

Preventive maintenance (man hour) is calculated according to the below formula

PMM = Number of times per year x Man-hours x Man-hour rate

Spare Parts Consumption (SPC) calculation

The spare parts consumption (SPC) calculation is the summation of the corrective maintenance SPC and preventive maintenance

Corrective Maintenance

The formula for average annual corrective maintenance spare parts (CMSP) consumption should be as following:

$$CMSP = \lambda T \times 8760 \times \text{Average corrective spares}$$

Where:
CMSP = Average annual corrective maintenance spares consumption.
λT = Total failure rate as number of failures per hour. This includes all failures. Equals to 1 / (Mean Time between Failures).
8760 = Number of hours in a year.
Average annual spares = Average spares needed for repair of the equipment.

Preventive Maintenance

The formula for average annual Preventive maintenance spare parts (CMSP) consumption should be as following:

PMSP = Number of times per year x Average spare parts consumption per PM routine

Logistics cost calculations

The total logistic cost estimated for the maintenance support of the system and /or equipment. It has been assumed to be fixed cost per year.

Energy cost calculation

Energy cost = Energy price $NOKKWHr$ x Power rating of equipment KWHr x Time of operation $houryear$

The energy consumption (KWH) for pump shall be calculated using the below formula

- $P_h = (q\,\rho\,g\,h / (\eta 1 * \eta 2 * (3.6\ 10^6)))$ (1)
- *Where*
- P_h = power (kW) q = flow capacity (m^3/h)
- ρ = density of fluid (kg/m^3) and g = gravity (9.81 m/s^2)

- h = differential head (m) $\eta 1$ = *shaft efficiency* $\eta 2$= *motor efficiency*

The underneath table shows the energy cost for the supplier A and B pumps

	Supplier A	**Supplier B**
q = flow capacity (m³/h)	25,00	27,00
ρ = density of fluid (kg/m3)	1000,00	1000,00
g = gravity (9.81 m/s2)	9,81	*9,81*
h = differential head (m)	20,00	22,00
η1= pump /shaft efficiency	0,55	0,60
H2 = motor efficiency	0,95	0,95
operation time	6000,00	6000,00
NOK/KWH	0,80	0,8
Energy cost per year	12482,074	13592,97857

Note:

The CO2 emission tax is not included in the energy calculation because the John Sverdrup is powered from the onshore.

The KWH price shall be around 0.8 NOK/KWH. The KWH tariff for the industrial purpose has been obtained from http://epp.eurostat.ec.europa.eu. The revealed price was in Euro and it was in 2011. So the 0,8 NOK/KWH obtained after using currency conversion and increasing the rate according to the actual inflation rate.

COST OF DEFFERED PRODUCTION (CDP)

According to the selected pump application, the pump failure does not have a direct CDP cost. It actually might have a non-significant cost.

The CDP is the occurred total cost of deferred production due to the probability of failure of system and equipment. The underneath formula shall be sued for the CDP calculation

Cost of deferred production (CDP) = E x p x D x L x CDP

Where:

CDP = Cost of Deferred Production.

E = Average number of critical failures per year.

p = Probability of production reduction.

D = Duration of production reduction. L = Quantity of production loss per time unit.

CDP = Cost of one hour downtime per year throughout the lifetime calculated as the difference in Net

Appendix E
Example of tank inspection check list

Tanks Inspection Checklist

This inspection should be completed every 3 months. Place an X in the appropriate box for each item. If any response requires additional elaboration, do so in the Descriptions and Comments space provided, or on a separate sheet of paper. If you answer YES on any question, describe the corrective action taken at the bottom of the page.

	YES	NO	CORRECTIVE ACTION
Tank surfaces show signs of leakage	______	______	________________
Tanks are damaged, rusted or deteriorated	______	______	________________
Bolts, rivets or seams are damaged	______	______	________________
Tank supports are deteriorated or buckled	______	______	________________
Tank foundations have eroded or settled	______	______	________________
Level gauges or alarms are inoperative	______	______	________________
Vents are obstructed	______	______	________________
Valve seals or gaskets are leaking	______	______	________________
Pipelines or supports are damaged	______	______	________________
Loading/unloading area is damaged	______	______	________________
Connections are not capped/blank-flanged	______	______	________________

Remarks:

____

____

____________________   ________________

Signature   Date

Example of leakage inspection check list

Visual Inspection Checklist for Piping Systems

Note: Piping systems also include injection points, pumps, compressors, valves, filters, tubing and tube fittings, connected mechanical equipment, instrumentation, and pipe support systems

1. IDENTIFICATION		
Circuit Unique ID Number:	Piping Line Number/Name:	Date:
Piping System Name:		Bldg:
Date of Inspection:	Work Order Number:	Pipe Specification #:
Inspector:	Employee Number:	Phone:
Comments:		

2. FIELD IDENTIFICATION	Yes	No	Location / Comment
Is piping labeled/tagged w/Equipment ID#?	☐	☐	
Is pipeline adequately identified?	☐	☐	
Are labels/tags readable?	☐	☐	
Do labels/tags need replacing?	☐	☐	
3. LEAKS	**Yes**	**No**	**Location / Comment**
Any leaks from the process?	☐	☐	
Any leaks from steam tracing?	☐	☐	
Are any valves leaking?	☐	☐	
Any leaks at leak repair clamps?	☐	☐	
Any evidence of past leaks?	☐	☐	
4. PIPE SUPPORT	**Yes**	**No**	**Location / Comment**
Any shoes off their supports?	☐	☐	
Any hangers missing or damaged?	☐	☐	
Any spring hangers bottomed-out?	☐	☐	
Any problems with support braces?	☐	☐	
*Any corrosion of supports?	☐	☐	
Any loose or broken brackets?	☐	☐	
5. VIBRATION	**Yes**	**No**	**Location / Comment**
Any significant vibration observed?	☐	☐	
Any evidence of excessive movement?	☐	☐	
Any pipe distortion observed?	☐	☐	
6. INSULATION **	**Yes**	**No**	**Location / Comment**
Any physical damage or penetration?	☐	☐	
Any deterioration/damage of weather seals?	☐	☐	
Any bulging or wet insulation?	☐	☐	
Any discoloration indicating leakage?	☐	☐	
Any retaining bands missing/broken?	☐	☐	
Any missing jackets, plugs, or insulation?	☐	☐	

7. CORROSION *	Severe	Mild	No	Location / Comment
Any corrosion at support points or fixtures?	☐	☐	☐	
Any coating or paint deterioration?	☐	☐	☐	
Any areas with scale, pits, or rust?	☐	☐	☐	
Any corrosion between flanges?	☐	☐	☐	
Any significant corrosion of flange bolts?	☐	☐	☐	