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**Cost-effective model for self-assessment of maintenance management: An update to the “Maintenance Baseline Study” early developed by Norwegian Petroleum Directorate.**

By

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## Abstract

The self-assessment method is used to improve the maintenance management system and its related operations. It has the advantage over the maintenance auditing method, as it is a self-driven improvement method, less required work and time consuming, and it keeps the assessment ownership within the department or the family-company. Therefore, the Norwegian Petroleum Directorate have developed a maintenance baseline study as a self-assessment tool for oil & gas industry in 1998. The maintenance baseline study provides a set of questions that help the maintenance manager to assess their whole maintenance management functions from strategic planning, program development, operational planning, execution management, reporting, analysis, until they could up an improvement plan & measures. This process looks like a management loop which has heavy interrelations within its internal functions. In fact, the maintenance baseline study is well known as maintenance management loop within the oil & gas industry.

In fact, Øxnevad & Nielsen (2000) illustrated the original wish of Norwegian Petroleum Directorate, when the Maintenance Baseline Study was developed, as to: (1) contribute to a general improvement of the quality of the operator's system for managing safety-related maintenance, (2) provide better predictability for the operators in terms of NPD's expectations and requirements in this area, (3) share the "best practices" and "state of the art" methods and techniques.

Therefore, the purpose of this thesis is to: (1) study the state of the art of the Maintenance Baseline Study, (2) extract the industrial needs for updating this tool and (3) develop a cost-effective model for self-assessment of maintenance management system based on the extracted needs and potential technologies.

This thesis is related to operation and maintenance hub meetings that are running by Cluster on Industrial Asset Management (CIAM) within University of Stavanger. The hub meetings gather managers and experts from wide range of Norwegian oil & gas industry in order to discuss specifically the maintenance baseline study (maintenance management loop developed by Norwegian Petroleum Directorate). Therefore, this thesis is relied on a semi-structural group meetings and discussions at the early stage and then a semi-structural interview to verify and validate the updated version of maintenance baseline study.

The updated version of maintenance baseline study has the following advantages: (1) it is user-friendly and easy to use, (2) it has a selective type of questions with integrated quantification of the answers, (3) it requires less time to conduct, (4) it provides user-friendly individual assessment, (5) it provides user-friendly group assessment, (6) it has an integrated method for linking the assessment into a SWOT analysis, (7) it is web-based and can be used on devices such as pc, mobile phone, iPad etc. which are connected to the internet and, (8) it can easily be modified and adapted.

The state of the art of the maintenance baseline study is clearly explored within this thesis. The exploration process based on interviews with the professionals in the field of maintenance management indicates, first, that the original version of the self-assessment method is considered as a basement for most of the self-assessment practices within O&G sector. However, it is not used in its original version by the large scale oil and gas operators have further developed their own customized self-assessment tool with help of modern technology e.g. web-based tools. The second issue, which can be concluded, is that large scale oil and gas operators is mainly interested to update the maintenance management loop, which is within the maintenance baseline study, with modern technology, tools and advanced maintenance techniques.

The industrial needs for updating the self-assessment tool of maintenance management are successfully extracted within this thesis. The first need is to enhance the maintenance supervision within the maintenance management loop by updating its link to the whole asset management loop e.g. PAS 55 standards and life cycle loop e.g. ISO 55001. The second need is to update the internal process of each function within the management loop that presented in Maintenance Baseline Study and to update the tools, technologies e.g. sensors, big data analytics, advanced maintenance techniques (Condition-based maintenance, Predict health monitoring, updated versions of Reliability & Risk centered maintenance, etc.). The third need is to improve the follow-up capabilities of the self-assessment tools in order to be more cost effective to perform the assessment process.

The cost-effective model for self-assessment of maintenance management system based on the extracted needs and potential technologies is sufficiently developed. The developed self-assessment tool based on the maintenance baseline study could show clear enhancement according to the experts' opinions as it requires less time, and it offers a user-friendly visualization of the collected/trended information and their associated results, offers an objective analysis and recommendation action generator.

In summary, several recommended future works have been highlighted in order to lead the further development into highly satisfying the NPD's wish of creating the general improvement of the management quality and excellence of safety-related maintenance operations and gain the benefit of sharing and updating the state of the art and best practice within the O&G sector.

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## List of abbreviations

CBM	Condition Based Maintenance
NCF	Norwegian Continental Shelf
NPD	Norwegian Petroleum Directorate
MMS	Maintenance Management System
MTTF	Mean Time to Failure
PSA	Petroleum Safety Authority
SWOT Analysis	Strengths Weaknesses Opportunities Threats Analysis

# 1. Introduction

## 1.1 Background and problem presentation

The demand for reliability is extremely high in oil and gas industry. Many companies in this industry work to a so-called ‘zero philosophy’, which means that their objective is to have zero accidents and injuries. Offshore operations in the Norwegian Continental Shelf (NCF) are technologically demanding and high-risk. The companies operating in this industry are high reliability organizations because they are engaged in sophisticated complex technologies that must be managed to avoid unanticipated interactions among parts of the organization. The oil and gas developments in this area are complex projects with many interfaces between different organizations, and oil and gas is produced in severe environments. Offshore oil and gas platforms are usually located in harsh environments hundreds of kilometres away from the land and conduct complex and dynamic operations. Failures in such operations may result in major accidents resulting in loss of human lives, oil spills, loss of equipment integrity etc. The cost of such accidents may be extremely high, as we have seen in the past in this industry. Deepwater Horizon disaster is a good example of this. Companies in this industry need to be able to manage and sustain almost error-free performance because errors and failures in them may lead to catastrophic consequences.

During the last decades, maintenance management has received an increased attention due to increased focus on safety and environmental issues, lower life-cycle-costs and overall profitability. That is why maintenance and effective maintenance management is an essential and significant component of operations with many benefits, including; the reduction of risks and downtime due to unexpected equipment failure, which improves reliability and maintainability, increasing equipment availability and utilization.

Consequently, the maintenance management concepts, approaches and operations have evolved over the last two decades. In 1996, “The Maintenance Baseline Study” project was initiated by the Norwegian Petroleum Directorate (NPD). This project was aimed to develop a method for a systematic and comprehensive assessment of the company’s own maintenance management system. At that time, Øxnevad & Nielsen (2000) highlighted that the use of self-assessment as a method for improving a company’s Maintenance Management System (MMS) has not been frequently applied by the companies operating in Norwegian Continental Shelf (NCF). The results of Maintenance Baseline study should contribute to a general improvement of the quality of the operator’s system for managing safety-related maintenance and in addition provide better predictability for the operators in terms of the NPD’s expectations and requirements in this area. (The Norwegian Petroleum Directorate, 1998). Øxnevad & Nielsen (2000) also highlighted four considerations of the “The Maintenance Baseline Study” project: insufficient internal maintenance supervision; insufficient follow-up capacity; need for better maintenance control and the need to allocate the new requirements related to more advanced maintenance techniques (Reliability centered maintenance, Risk based inspection, etc.). After 20 years since the development of the Maintenance Baseline Study, some of these considerations are still valid and highlight the need for further updating

of the Maintenance Baseline Study. The modern considerations contributed to this thesis work can be summarized as follows:

1. There is a need to enhance the maintenance supervision within the maintenance management loop by updating its link to the whole asset management loop e.g. PAS 55 standards and life cycle loop e.g. ISO 55001.
2. There is a need to update the internal process of each function within the management loop that presented in Maintenance Baseline Study and to update the tools, technologies e.g. sensors, big data analytics, advanced maintenance techniques (Condition-based maintenance, Predict health monitoring, updated versions of Reliability & Risk centered maintenance, etc.)
3. There is a need to improve the follow-up capabilities of the self-assessment tools in order to be more cost effective to perform the assessment process. The self-assessment style of the Maintenance Baseline Study, in its current form, is time consuming due to the technical issues: large number of questions, their level of clarity, variations in the response styles and lack of analysis that can follow to summaries the results. Moreover, there is a need to enhance the cross-assessment, results sharing and illustration between responsible departments with the same company.

## 1.2 Objectives

The first two improvement requirements are related to the maintenance management loop by itself. However, it is the most critical requirement among the above three highlighted requirements since it is required to be taken either with current maintenance management loop or for the updated maintenance management loop (i.e. considering asset management and life cycle perspectives and their associated technologies and tools). Even though, it could be that several large scale oil& gas operators have within the last 20 years already developed further their own customized self-assessment tools for their maintenance operations, the literature is quite empty of any report or study that could provide us an update of the “best practices” and “state of the art” of this method. In fact, Øxnevad & Nielsen (2000) illustrated the original wish of Norwegian Petroleum Directorate, when the Maintenance Baseline Study was developed, as to: (1) contribute to a general improvement of the quality of the operator’s system for managing safety-related maintenance, (2) provide better predictability for the operators in terms of NPD’s expectations and requirements in this area, (3) share the “best practices” and “state of the art” methods and techniques. Therefore, the research question can be formulated as follows:

*How can maintenance baseline study be enhanced in a cost-effective manner e.g. time saving, user-friendly, automated analysis and recommendation action generating?*

Consequently, the purpose of this thesis is to: (1) study the state of the art of the Maintenance Baseline Study, (2) extract the industrial needs for updating this tool and (3) develop a cost-effective model for self-assessment of maintenance management system based on the extracted needs and potential technologies.

### **1.3 Methodology**

This section shows the development method used in the thesis. The development method consists of the following steps:

1. Investigate the literature in the field of maintenance management and explore the state of the art with the industry (based on hubs' discussions and personal contacts)
2. Extract the industrial need for improvements
3. Explore and evaluate several conceptual solutions to satisfy the industrial needs
4. Develop the selected solutions and illustrate the developments
5. Verify the developed model with experts
6. Validate the developed model with experts

Application of these steps should help to develop a cost-effective model for self-assessment of maintenance management system based on the extracted needs and potential technologies.

### **1.4 Limitations / Delimitations**

This project is a master thesis and has a limited amount of time. The given time frame stretches from 1 February to June 15, which is the submission date. During this time period, everything from planning till writing the final report must be done.

The study was delimited by:

- Selecting the third requirement of improvement as described above
- Limiting the conceptual solutions to three
- Limiting the criteria
- Selecting three functions within the maintenance management loop to show the development
- Implementing verification and validation method based on general feedback and limiting the interview with purposefully selected experts
- Limiting the model development to develop a semi-integrated tool

### **1.5 The structure of the thesis**

The structure will follow the example in the guide for students on how to write a master thesis developed by UiS. The thesis includes five chapters. Chapter one is an introduction of the thesis which consist of the sections which are related to the outlining of the background and objective for the work. Chapter two presents theory related to the maintenance and maintenance management, maintenance assessment and auditing, improvement process, and decision-making process. Chapter three presents data collection and development analysis which include requirement analysis, conceptual solutions analysis, verification and validation analysis. In chapter four, we have provided demonstration for the developed model and

followed by critical discussions. Finally, in chapter five, the conclusions were drawn up based on the work of the thesis in a comprehensive way.

## 2. Theory and literature review

This chapter aims to provide the required theoretical background that are needed to understand the whole research work within this thesis. Therefore, it starts with a general theory about maintenance and maintenance management, and then describes maintenance assessment methods and auditing, improvement process and decision-making process. Finally, this chapter is ended with the theory about system development in order to understand the model development within this thesis.

### 2.1 Maintenance

There are many definitions to maintenance. Manzini, et al. (2010), defines maintenance as the function that monitors and keeps plant, equipment, and facilities working. It involves preventive (planned) and corrective (unplanned) actions which are carried out to retain a system in or restore it to an acceptable operating condition. According to EN 13306 (2001), Maintenance can be defined as the “combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function”. According to Mobley (2002), maintenance costs are a major part of the total operating costs of all manufacturing and production plants. Depending on the specific industry, maintenance costs can represent from 15% to 40% of the costs of goods produced. Recent surveys of maintenance management effectiveness indicate that one third of all maintenance costs is wasted as the result of unnecessary or improperly carried out maintenance (Mobley, 2002). Ineffective maintenance management represents a large monetary loss for companies, which in turn dramatically impacts their ability to manufacture quality products that are competitive in the world market. Inadequate maintenance can result in loss of production time, product quality and impose serious risks for humans and environment (Mobley, 2002). If maintenance performed properly, it can help to reduce risks and production costs, minimize problems, increase productivity, and improve quality (Manzini, et al., 2010). As the global competition increases and society grows in complexity and interdependence, the role of maintenance will grow in importance, which in turn will necessitate for increased and improved maintenance actions in the near future. The main focus will be on improving safety, reducing production costs, increasing efficiency, and improving quality of products and processes (Manzini, et al., 2010).

According to Mobley (2002), maintenance in industrial and process plants can typically be classified into three major categories and figure 1 illustrates that:

- Corrective (run-to-failure): where the parts are replaced after being broken;
- Preventive maintenance: scheduled maintenance, where the parts are replaced at fixed intervals and;
- Predictive (condition-based) maintenance: where the condition of the system is monitored.



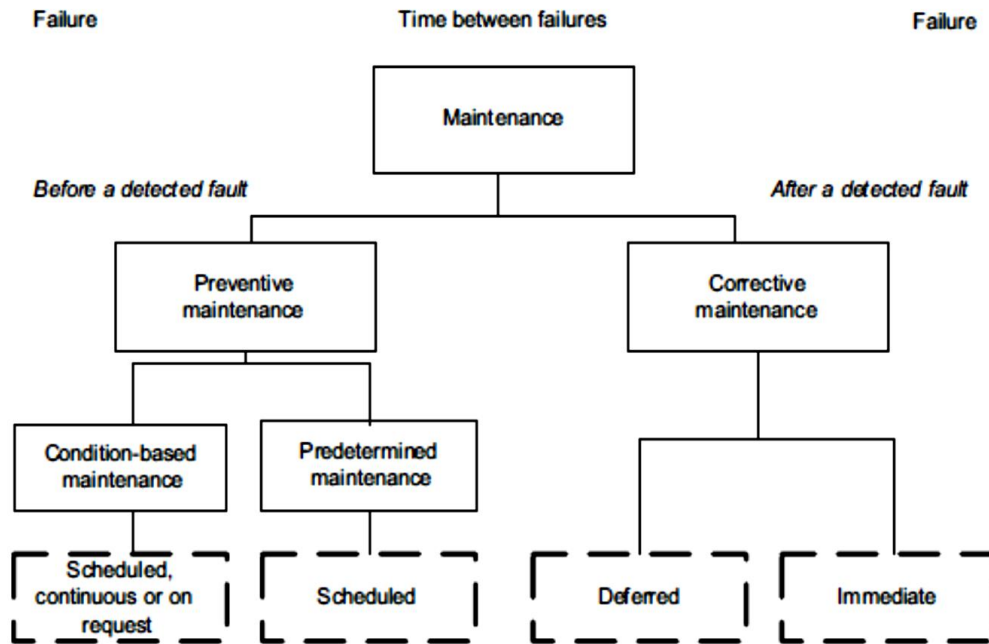


Figure 1 Maintenance strategic overview (EN 13306, 2001)

### 2.1.1 Corrective (Run-To-Failure Strategy)

In run-to-failure strategy, a machine is repaired when it breaks down. There is no spend of money on maintenance activities until a machine or system failure occurs. This is a reactive technique which means that it waits for a machine, equipment or system failure before any maintenance action is initiated. It is true that it is the most expensive method of maintenance management, and the major expenses associated with this type of maintenance management are:

- High spare parts inventory cost
- High overtime labour costs
- High machine downtime
- Low production availability

Because there is no attempt to anticipate maintenance requirements in a plant that uses run-to-failure strategy, it must be able to react to all possible machine, equipment and system failures within the plant. The result is that the maintenance department is forced to maintain extensive spare parts inventories including spare machines or at least all major components for all critical equipment in the plant (Mobley, 2002). Since unexpected machine and equipment failures impact the production, maintenance personnel must be able to react immediately to all machine failures, which in turn results in increased maintenance costs, lower availability of process machinery, loss of production etc. In contrast, scheduling the repair would provide the ability to minimize the repair time and associated labour costs. It also would provide the means of reducing the negative impact of expedited shipments and lost production (Mobley, 1990).

## 2.1.2 Preventive Maintenance Strategy

The preventive maintenance strategy is time-driven where maintenance tasks are based on elapsed time or hours of operation. Figure 2 illustrates an example of the statistical life of a machine –train. The mean-time-to-failure (MTTF) of bathtub curve indicates that a new machine has a high probability of failure, due to installation problems, during the first few weeks of operation. Following this initial period, the probability of failure is relatively low for an extended period of time. Following this normal machine life period, the probability of failure increases sharply with elapsed time. In preventive maintenance management, machine repairs or rebuilds are scheduled based on the MTTF statistic. (Mobley, 1990).

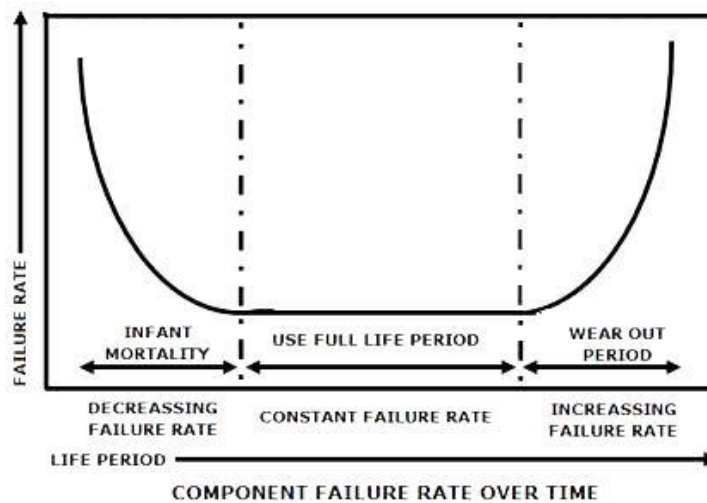


Figure 2 Bathtub curve (Mobley, 1990)

Preventive maintenance is aimed to try to maintain the equipment in optimum working condition and to prevent any unplanned downtime due to breakdowns. It includes measuring and checking components as well as the replacement of various components after a given operational time-interval (Mobley, 1990). An example of this effort could be replacement of the timing belt on the car. Everything wears over time and the costs of replacing some items prior to their actual failure are much less than the potential consequences of the failure itself whilst in service. Back to our example, many car engines would suffer significant damage if the timing belt broke, and we would incur far greater expense than if we had just replaced the belt prior to failure (Lean Manufacturing Tools, 2016).

## 2.1.3 Predictive (Condition Based) Maintenance (CBM)

According to Mobley (2002), predictive maintenance is a condition-driven preventive maintenance program, where instead of relying on industrial or in-plant average-life statistics (i.e., mean-time-to-failure) to schedule maintenance activities, predictive maintenance uses direct monitoring of the mechanical condition, system efficiency, and other indicators to determine the actual mean-time-to-failure or loss of efficiency for each machine-train and system in the plant. Predictive maintenance is the regular monitoring of the actual mechanical condition, operating efficiency, and other indicators of the operating condition of machine-trains and process systems, which will provide the necessary data required to ensure the

maximum interval between repairs and minimize the number and cost of unscheduled outages created by machine-train failures. Predictive maintenance can include monitoring the vibration of rotating machinery in attempt to detect incipient problems and to prevent catastrophic failures, monitoring the infrared image of electrical switchgear, motors, and other electrical equipment to detect developing problems, etc. Predictive maintenance can help to improve productivity, product quality, and the overall effectiveness of manufacturing and production plants (Mobley, 2002). It is the means of improving productivity, product quality, and overall effectiveness of manufacturing and production plants. It uses the most cost-effective tools like visual inspection, process parameter monitoring, vibration analysis, thermography, and tribology to obtain the actual operating condition of critical equipment and plant systems. Based on the obtained data, maintenance activities can be scheduled on an as-needed basis. The result of this effort will be optimized availability of process machinery, reduced costs associated with maintenance, improved quality, productivity and the overall profitability of manufacturing or production plants (Mobley, 2002).

## 2.2 Maintenance Management

Maintenance management can be defined in many ways. According to EN 13306 (2001), maintenance management is defined as:

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

It is the process of leading and directing the maintenance organization. Marquez (2007) defines maintenance management as:

*“All the activities of the management that determine the maintenance objectives or priorities (defined as targets assigned and accepted by the management and maintenance department), strategies (defined as a management method in order to achieve maintenance objectives), and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, and several improving methods including economical aspects in the organization.”*

Maintenance management is the process of overseeing maintenance resources in order to avoid downtime from broken machines and equipment or waste of money on inadequate maintenance activities. Facilities with their machines, equipment and systems suffer wear and tear, damage and destruction. The primary objectives of maintenance management are to control costs, schedule maintenance activities in an effective and efficient way, and ensure regulatory compliance. Poorly organized maintenance program can impose risks of major incidents, damage and accidents to a company and that is why a proper maintenance management is so essential to the success of any company or organization.

## 2.2.1 The Generic Maintenance Management Process

When the maintenance strategic planning is done and the series of target maintenance performance measures exist, a generic budget is assigned to maintenance, and the high-level management and organizational responsibilities for specific maintenance activities are established, then the next steps that are needed to follow in order to manage maintenance properly could consist of the following sequential management steps suggested by Marquez (2007):

- Asset maintenance planning:
  - Identify the asset;
  - Prioritize the asset according to maintenance strategy;
  - Identify its performance requirements according to strategy;
  - Evaluate the asset's current performance;
  - Plan for its maintenance;
- Schedule maintenance operations:
  - Identify and assign personnel;
  - Acquire materials and spare parts from inventory or external sources;
  - Ensure that tools, transportation, lifting and support equipment are available;
  - Prepare required operating, maintenance, safety and environmental procedures and work plans;
  - Identify and reserve external resources;
  - Identify communication resources;
  - Provide necessary training.
- Manage maintenance actions execution:
  - Gather technical data and task description;
  - Obtain spare parts and tools and support equipment;
  - Travel to the worksite;
  - Prepare the worksite (equipment shutdown, isolation and lockout procedures);
  - Active maintenance time;
  - Observe and measure;
  - Test and checkout;
  - Clear the worksite;
  - Record necessary information.
- Assess maintenance:
  - Production capacity;
  - Availability of equipment or production;
  - Downtime or outages;
  - Safety and environmental performance;
  - Regulatory compliance;
  - Operating cost;
  - Maintenance cost;

- Corporate profit;
- Product quality
- Etc.
- Ensure continuous improvement:
  - Level of maintenance;
  - Maintenance procedures;
  - Skills and training of maintenance and operations personnel;
  - Spare parts and materials;
  - Tools and support equipment;
  - Use of external resources;
  - Operating procedures and conditions;
  - Safety and environmental procedures;
  - Equipment and system design;
  - Maintainability of the equipment.
- Consider the possibility of equipment re-design.

### 2.2.2 Challenges Associated with Maintenance Management

There are a wide range of difficulties associated with maintenance management which indicate that it is not so easy to manage this function. Marquez (2007), after having carried out a literature review on this topic has identified the following challenges associated with maintenance management:

- *Lack of maintenance management models.* There are no models that could help to improve the understanding of the underlying dimensions of maintenance;
- *Wide diversification in the maintenance problems.* It is very difficult to find procedures and information support system in one place to ease the improvement process, as there is normally a very wide diversification in the problems that maintenance encounters and the high level of variety in the technology used;
- *Lack of plant/process knowledge and data.* Managers, supervisors and operators find that the lack of plant and process knowledge is the main constraint followed by the lack of historical data, which is critical for proper implementation of suitable maintenance policies;
- *Lack of time to complete the analysis required.* Day to day actions and associated decision-making activities distract managers from the fundamental activities aimed to improve maintenance;
- *Lack of top management support.* Other common causes of maintenance underdevelopment in organizations are lack of leadership to foster maintenance improvement programs, fear of an increase in production disruptions, etc.;
- *The implementation of advanced manufacturing technologies.* In recent decades, the nature of production environment has changed due to implementation of advanced manufacturing technologies and just-in-time production systems. Because of this development, many companies can manufacture products massively in a customized and highly efficient way. However, the maintenance system is put on pressure as automation is increased and buffers of inventory in the

plants have been reduced. Highly automated plants have limitations of computer controls and the integrated nature of the equipment. That is why it is needed an extensive knowledge which makes it difficult to diagnose and solve equipment problems. The disruption to production flows can be costly.

- *Existent safety and environmental factors.* Emerging regulations put pressure on maintenance managers and add complexity to this function.

## 2.3 Maintenance assessment

### 2.3.1 Maintenance Auditing method

Maintenance auditing is important for many facility owners around the world because it helps to identify and know the status of the maintenance management system. Auditing helps to measure and improve the effectiveness of the maintenance management system. In maintenance auditing, different functions are analyzed and evaluated with respect to efficiency, effectiveness, processes, methods etc. Every company or organization need to:

- Be cost-effective.
- Know how good they are, and how good they can become.
- Know how well do they plan and schedule.
- Know how well do they perform and complete.
- Etc.

The purpose and objectives of the maintenance audit include:

- Enhance productivity.
- Decrease overtime.
- Decrease in paperwork.
- Enhance equipment availability.
- Minimize downtime.
- Decrease parts inventory costs.
- Etc.

Maintenance audits can help to evaluate the performance of maintenance functions and determine the need for a consistent maintenance strategy, as well as to evaluate the performance of the maintenance functions after strategy implementation. Other benefits of maintenance audit may include:

- Management will get a better vision of maintenance operation with respect to maintenance management and processes.
- Weaknesses and strengths of maintenance management and process will be better understood.
- Reduction of maintenance costs.
- Etc.

The maintenance audit process is conducted on site and reviews key elements methodically, and this is usually done by:

- Interviewing key employee in the organization, including chosen suppliers and chosen contractors.
- Conducting site inspections of equipment and facilities.
- Reviewing process flows and mapping maintenance functions and controls.
- Reviewing stores management, documentation management, and control.

### **2.3.2 Maintenance self-assessment method: Maintenance Baseline Study**

The Maintenance Baseline study was a project initiated by the Norwegian Petroleum Directorate (NPD) in 1996. This project was aimed to develop a method for a systematic and comprehensive assessment of the company's own maintenance management system. At that time, the use of self-assessment as a method for improving a company's Maintenance Management System (MMS) has not been frequently applied by the companies operating in Norwegian Continental Shelf (NCF). The results of Maintenance Baseline study should contribute to a general improvement of the quality of the operator's system for managing safety-related maintenance and in addition provide better predictability for the operators in terms of the NPD's expectations and requirements in this area (The Norwegian Petroleum Directorate, 1998).

According to NPD (1998), several considerations contributed to this project being initiated:

- Insufficient internal supervision in the companies of the maintenance function
- Insufficient capacity in the NPD to follow up every single field
- The need for stronger control of maintenance on installations nearing their final phase of operation
- New requirements related to a control system when introducing more advanced optimization techniques

The NPD observed that there was no common understanding in the industry of what a MMS really is. Therefore, a model for MMS was designed that would be recognized and accepted by the petroleum industry in Norway. After having assessed their own maintenance management systems according to this method, the companies would have a documented basis for improving their management systems (The Norwegian Petroleum Directorate, 1998).

#### **2.3.2.1 Management loop within maintenance baseline study**

The baseline-study was intended as a tool for continuous improvement of the operator's own system for managing safety-related maintenance. The information obtained from the baseline-studies shall be used by authorities in improving the decision-making basis when selecting focus areas as regards maintenance, and in prioritizing supervision of operators and fields. The Maintenance Baseline Study was intended to provide a common understanding of the management system's strength, weaknesses and improvement areas and form the basis for further communication and follow-up both for operators and authorities. The Maintenance Baseline study was mainly focused on the quality of the maintenance system as regards



maintaining technical condition and safe operation in the operating phase of installations (The Norwegian Petroleum Directorate, 1998). Figure 3 below illustrates the maintenance management loop developed by NPD.

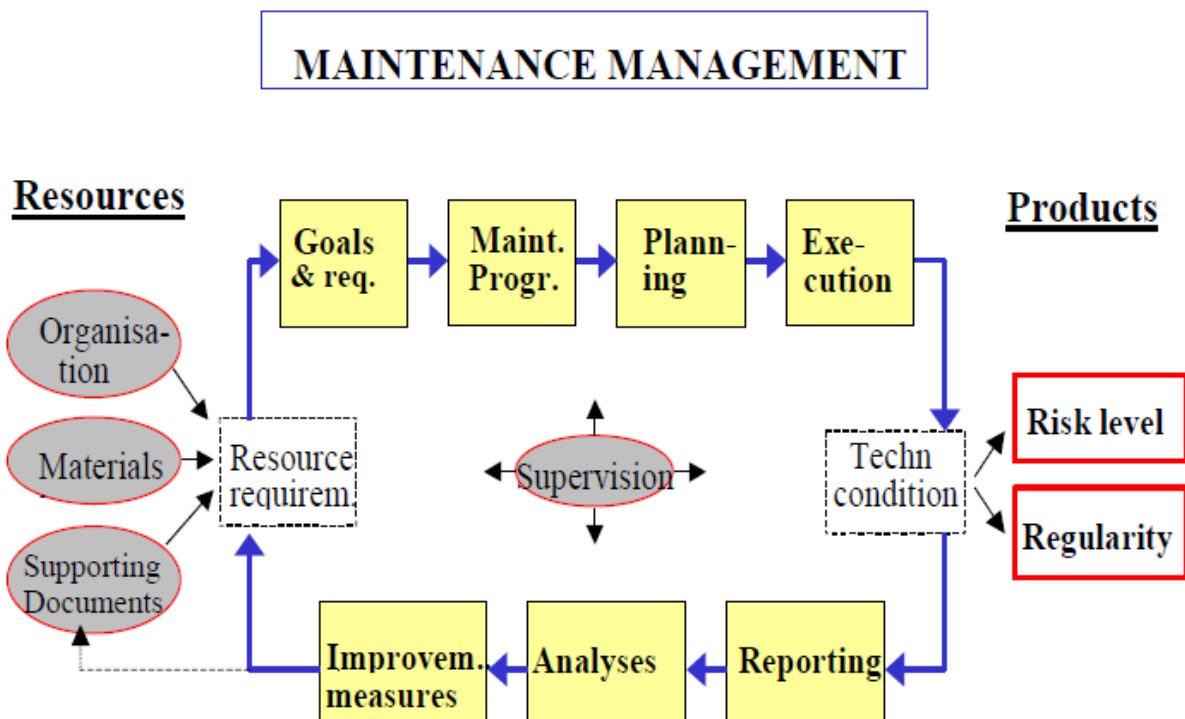


Figure 3 Maintenance Management Loop (The Norwegian Petroleum Directorate, 1998)

This is a model in which the management of safety-related maintenance is presented as an overall process (management loop) which, by means of necessary mobilization of resources, produces safety (low risk) and high availability/regularity. For each process element in the model, there is devoted own chapter. Each chapter starts with a description of the process element together with comments from the NPD concerning observations from supervisory activities connected to this element. Then, a list of detailed questions about the status of the special element in the company performing the assessment follows (The Norwegian Petroleum Directorate, 1998).

### 2.3.2.2 Self-assessment of maintenance operations

The generic process of the use of the self-assessment method of maintenance management system can be described briefly in five steps and illustrated in figure 4:

1. Read and analyze the questions
2. Generate the answers
3. Report the answers
4. Analyze the answers and identify improvement areas
5. Implement necessary actions aimed to improve the system





*Figure 4 Generic process of use of the self-assessment method*

As we can observe from figures four and five, this process requires a lot of time and effort from the individual performing the self-assessment of maintenance management system. This is because he or she is required to write down both the questions and the answers and need time to analyze and understand the questions and the answers due to the answering style of the self-assessment method. This can be challenging since many managers in the field of maintenance management indicate how they do not have the required time to carry out suitable analysis due to day to day actions and decision-making activities which distract them from the fundamental activities to improve the maintenance management system (Marquez, 2007).

## **2.4 Improvement process based on assessment results**

The 7-step improvement process will be briefly described in this sub-chapter. It follows the steps outlined in figure 5.

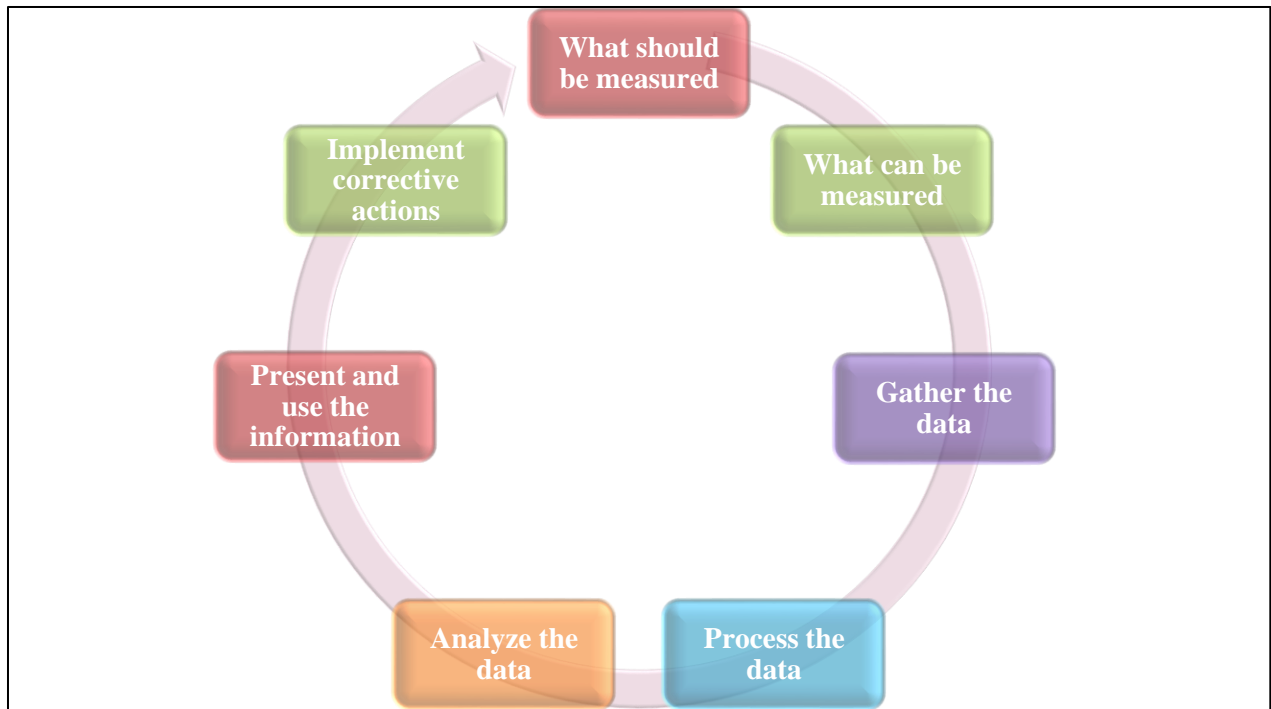


Figure 5 Seven step improvement process

Step 1: What should be measured?

The configuration of the system must be measured in order to compare it before and after the change. In this step, the key performance indicators are deduced from critical success factors which are the important goals for the organization running the system. A list of key performance indicators should be created. These will tell us what should be measured (ZHAW Zurich University of Applied Science, 2013)

According to Green (2016), the main two questions that are needed to be asked at this first step are:

- What types of business outcome need to be achieved?
- What are the current and future business requirements?

Step 2: What can be measured?

Next step is to consider how a list of aspects can be measured. The performance metrics for the key performance indicators should be defined. Not all performance indicators can be measured directly. In order to measure a system, metrics for every indicator must be constructed (ZHAW Zurich University of Applied Science, 2013). Green (2016) states that “at this step, you need to identify what your existing tools and resource capabilities are and ask yourself: What are our current processes, and how do we need to measure those?”

Step 3: Gather data

Collect the data to assign values to the metrics using data-gathering techniques. Measure the data and organize it (Green, 2016).

#### Step 4: Process the data

In order to analyze the collected data, it should be processed. After data gathering process, the findings should be addressed. The data need to be turned into information that makes sense and enables you to make an analysis (Green, 2016).

#### Step 5: Analyze the data

At this step, you need to analyze the data and identify any positive or negative trends. The identified trends need to be documented and the report should be provided (Green, 2016).

#### Step 6: Present and use the information

The information that you obtained need to be presented. At this step, you need to pay attention to your potential audience and adapt the presentation accordingly. For example, your CEO or CFO probably do not need high level of technical details. The information that you present should be useful and easy to understand and interpret (Green, 2016).

#### Step 7: Implement corrective action

At this last step, corrective actions should be implemented. These actions will depend on the information generated in previous steps. The whole team should be involved at this step.

### **2.4.1 Feedback gathering**

Different options are available aimed to gather a feedback and one of them is a Survey, a method which is used to collect information about a topic of interest. There are different types of surveys and they are roughly divided into two broad areas: Interviews and Questionnaires.

#### **2.4.1.1 Interviews**

Interviews can be defined as a qualitative research technique involving individual interviews with a small number of respondents aimed to explore their perspectives on a particular topic, idea etc. (Boyce and Neale, 2006, p.3) cited in (Research Methodology, 2016).

According to Research Methodology (2016), there are three different formats of interview:

- Structured interviews: Consist of a series of re-determined questions that all interviewees answer in the same order. Here, the data analysis usually tends to be more straightforward compared to other forms of interviews. This is because the researcher is able to compare and contrast different answers given to the same question.
- Unstructured interviews: The least reliable form of interviews from the researchers' viewpoint. This is because no questions are prepared prior to the interview and the interview is conducted in an informal manner. Here, the comparison of answers given by different respondents tends to be difficult due to the differences in formulation of questions.

- Semi-structured interviews: Contain components of both, structured and unstructured interviews. Here, the interviewer prepares a set of same questions to be answered by all interviewees, but additionally questions might be asked during interviews to clarify or further expand certain issues.

#### 2.4.1.2 Questionnaires

According to (Research Methodology, 2016), there are mainly following types of questionnaires:

Computer questionnaire. In this type of questionnaire, respondents are asked to answer the questionnaire which is sent to them by mail. This type of questionnaire has several advantages which include low or no cost, time saved and spared, no pressure on respondents by having an opportunity to answer questions when they have time and when it is convenient for them. However, the main shortcoming of this type of questionnaire is that in some cases, respondents may not bother answering the questions and can just ignore the questionnaire.

Telephone questionnaire. Researcher calls to potential respondents so that they answer to the questionnaire. The main advantage here is that, it can be completed during the short amounts of time. The main disadvantage is that most people do not feel comfortable to answer many questions asked through the phone and it is not easy to get a sample group to answer questionnaire over the phone.

In house survey. This type of questionnaire involves for the researcher visiting respondents in their workplaces or house. The main advantage here is that more focus towards the questions can be gained from respondents. The main disadvantages here are that in-house survey is time consuming, respondents may not wish to have researchers in their houses or workplaces for various reasons.

#### 2.4.2 Identify and illustrate the improvement needs

There are several different types of analysis approaches that are available for identifying and illustrating the improvement needs. One of them is a SWOT analysis, which is a structured planning method that lets to define the objective of the business, internal and external factors that are favourable or unfavourable for achieving this objective (Conceptdraw, 2017). It is a process that helps to identify an organization's strengths, weaknesses, opportunities and threats. A SWOT analysis determines what assists the company in accomplishing its objectives, and what obstacles must be overcome or minimized to achieve desired results (Investopedia, 2017). It represents strengths, weaknesses, opportunities, and threats on the SWOT Matrix, and can be conducted for an industry, company, product, place or person. With the help of the results from the SWOT analysis, we can assess if the company does have the internal forces and resources to realize the existing opportunities and resist external threats, and what internal deficiencies require the prompt rectification (Conceptdraw, 2017). Figure 6 below illustrates the SWOT analysis framework.

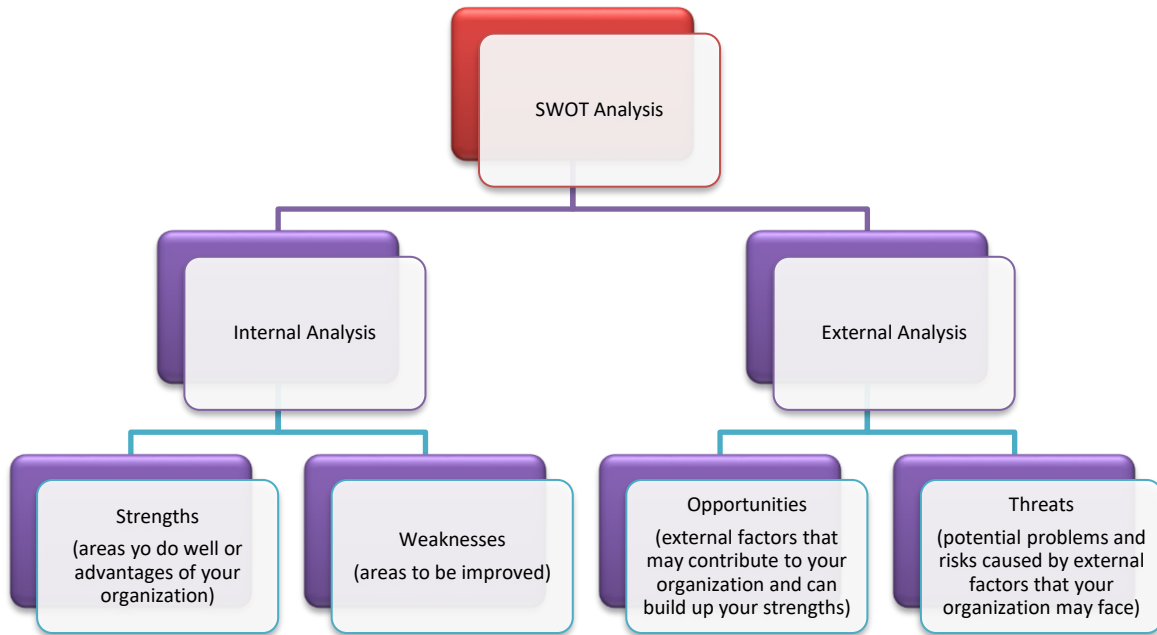


Figure 6 SWOT Analysis framework

Berry (2017) describes these four elements of a SWOT analysis as follows: “**Strengths (internal, positive factors)**: Positive attributes, tangible and intangible, internal to the organization and which are within your control.

**Weaknesses (internal, negative factors)**: Aspects of your business that detract from the value you offer or place you at a competitive disadvantage. These areas need to be enhanced in order to compete with your best competitor.

**Opportunities (external, positive factors)**: External attractive factors that represent reasons your business is likely to prosper.

**Threats (external, negative factors)**: External factors beyond your control that could place your strategy, or the business itself at risk. You have no control over these, but you may benefit by having contingency plans to address them if they should occur”.

The other tools that are used to find out an organization’s current status and position are PEST, STEEP and STEEPLE analyses. These tools help to assess the company’s external environment and current role.

**PEST analysis** is similar to SWOT analysis in that it studies the same four dimensions. However, the factors considered in PEST are political, economic, social, and technological. This analysis helps to understand how each of the factors impacts business. PEST analysis studies the opportunities and threats section of SWOT, but in more detail (Pestleanalysis, 2015).

**STEEP analysis** is a tool commonly used in marketing to evaluate different external factors which impact an organization. This analysis tool allows you to get a detailed overview on

what external factors determine the trends. It is basically an acronym which stands for Social, Technological, Economical, Environmental, and Political (Pestleanalysis, 2015).

**STEEPLE analysis** includes in addition the study of the legal and ethical factors. Legal factors include legal restraints and regulation, health and safety of employees. Ethical factors are about the social values, which govern business behaviour (Pestleanalysis, 2015).

### 2.5 Decision making process

The following 8-step multi-objective decision-making process developed by Bratvold & Begg (2010) will be utilized in the concept generation process as illustrated in figure 7:

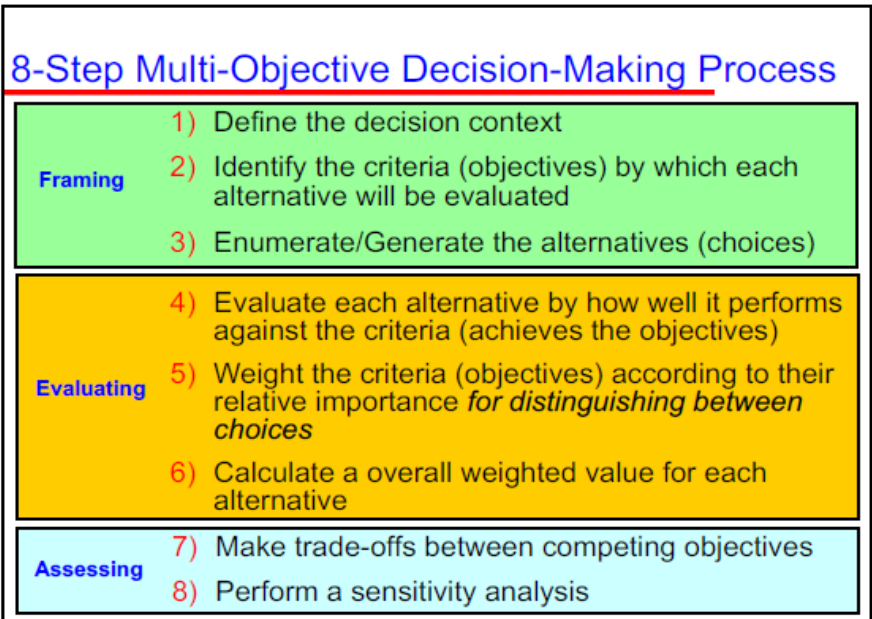


Figure 7 8-step multi-objective decision-making process (Bratvold & Begg, 2010)

Only those criteria that are relevant for choosing between alternatives will be used in the decision-making process. The importance of criteria will be subjectively ranked as illustrated in table 1 by applying relative weights from zero to 100. All the scores will be summed and normalized to one. Since this is a simple decision-making process with few criteria and alternatives, which are not so complex and do not involve high costs, the steps involving the trade-offs and sensitivity analysis will not be performed.

Table 1 Weighting approach template

Criteria	Rank	Weight	Normalized
<b>Sum</b>			

Next step is to identify and assess alternatives against criteria. Each alternative will be rated against each criteria using the attribute scales. The following template illustrated in figure 8 for implementing and recording will be used in decision-making process:

1. Define Context & Decision			
Objectives			Alternatives
Name	Rank	Wt	
2. List your Objectives or Criteria.			3. List the choices
		5. Weight Your Obj.s	4. Score how each Alternative "performs" against each Objective →
Total Score			6. Calculate weighted score for each alternative

Figure 8 Template for decision-making process (Bratvold & Begg, 2010)

## 3. Data collection and development Analysis

### 3.1 State-of- the-practice analysis of the self-assessment method

This section will show and describe the current use of the self-assessment method. The questions in the self-assessment method are intended to help create ideas and it is up to individual company to focus on questions and issues that, in the company's opinion, are important for improvement purposes. This is a method in which the management of safety-related maintenance is presented as an overall process (management loop) which, by means of necessary mobilization of resources, produces safety (low risk) and high availability/regularity. For each process element in the model, there is devoted own chapter. Each chapter starts with a description of the process element together with comments from the NPD concerning observations from supervisory activities connected to this element. Then, a list of detailed questions about the status of the special element in the company performing the assessment follows (The Norwegian Petroleum Directorate, 1998). Figure 9 and 10 illustrate how the self-assessment method is build up and the question styles. Figure 11 illustrates the processes associated to current use of the self-assessment method.

#### *Preventive maintenance programme*

How does it appear from the basic material for preparation of preventive maintenance programme:

- which safety-critical failure modes the programme is intended to prevent?
- which degradation mechanisms are to be prevented/observed?
- when reduced performance/availability brings a system/equipment into a failure modus?
- which assumptions are made in the total risk analysis in terms of :
  - the reliability/testing frequency etc. of the safety systems
  - the technical conditions of equipment, which in the event of failure could trigger an accident (leaks, etc.)?

Figure 9 A snapshot of the self-assessment method 1 (The Norwegian Petroleum Directorate, 1998)

#### **Programme**

The chapter focuses on work processes for development, updating and improvement of preventive maintenance programmes, inspection programmes, programme for condition assessment and testing, etc. In the following text, preventive maintenance is often used as a designation for these programmes combined.



**Comments:** The NPD has registered large differences between the companies, both as regards the size of the total resources that are made available for development and updating of maintenance programmes, and the methods, standards, etc. that are used for this purpose.

#### *Strategies and methods- reliability-based maintenance - (RCM), risk-based inspection (RBI)*

- Are the company's strategies and methods for preparation of a programme for preventive maintenance, inspection, testing, etc. clearly expressed and communicated to the relevant units?
- Are the strategies based on recognised standards or tested methods from other companies/ other industry?
- To what extent are sufficient resources made available (skills, time, tools) to apply these strategies and methods in practice?
- Are the existing empirical data (equipment failure frequencies, causes of failures, etc.) sufficiently reliable in relation to the applied methods?
  - Are requirements relating to registering of failure data (type, equipment, level of detail, etc.) adjusted in accordance with the identified requirements when classifying criticality and preparing preventive maintenance programmes?
  - Are personnel with operative experience used to qualify empirical data, etc.?

Figure 10 A snapshot of the self-assessment method 2 (The Norwegian Petroleum Directorate, 1998)



A literature review has been performed in order to review a number of papers in the field of maintenance management and identify different methods for self-assessment of maintenance management system aimed to help oil and gas companies assess their own maintenance management strategies. There were a few amounts of relevant published research available concerning the self-assessment of maintenance management system. There are no other self-assessment methods available for self-assessing maintenance management system than that which is developed by NPD.

Interviews with the experts in the field of maintenance management indicate that the self-assessment method is a good tool for the self-assessment of maintenance management system and is used by the oil and gas operating companies. However, it is not user-friendly and not easy to use in practice. Other observations are that the maintenance management concepts, approaches and operations have evolved over the last two decades. Thus, there is first needed to update the maintenance management loop by updating its link to the whole asset management loop and life cycle loop. Second, there is a need to update the internal process of each function of the management loop that is presented in the baseline study by NPD and to update the tools and technologies that are used to perform those functions. These two improvement requirements are related to the management loop by itself. However, there is a third direction of improvement which is related to the self-assessment part of the maintenance baseline study. The self-assessment method with its current form is time consuming due to the number of questions, their level of clarity, variation in the response style and type of analysis that summaries the results and illustrates the recommended actions. Therefore, managing the self-assessment process is the third requirement for the improvement. However, it is the most critical requirement among the three highlighted requirements since it is required to be taken either with current maintenance management loop or for the updated maintenance management loop (i.e. considering asset management and life cycle perspectives and their associated technologies and tools).



Figure 11 Current use of self-assessment method

The last two blocks of the current self-assessment method illustrated on figure 11 are very poor. There is no integrated analysis approach in the current self-assessment method based on which the improvement areas could be identified, and the necessary improvement measures could be implemented.

### 3.2 Requirements analysis

There is a need for finding an appropriate fit between the user of the self-assessment method and the self-assessment method itself. The user's capabilities as well as limitations need to be considered so that the self-assessment method is utilized effectively. In order to evaluate or assess the fit between the user and the self-assessment method, the job activity being done, as well as the demands of users need to be considered. The self-assessment method in its current state is not user-friendly and is time consuming. Questions need to have higher degree of clarity so that they are clear and understandable for the individual conducting the self-assessment of the maintenance management system. Generating possible answer alternatives where appropriate would also make it easier to perform the self-assessment and reduce the time spent on it. Also, the amount of questions can be reduced after proper analysis, so that there are no duplicate questions.

After analyzing the self-assessment method, the following requirements for improvement are observed and collected in Table 2:

*Table 2 Requirements and criteria for improvement of the self-assessment method*

<b>Stakeholder</b>	<b>Requirement</b>	<b>Criteria</b>
User	The self-assessment method should be user-friendly for operations and maintenance managers	User-friendly
User	The self-assessment method shall require less time to conduct	Use of time
User	There should be generated possible answer alternatives where appropriate	Answer alternatives
User	The amount of questions shall be reduced if possible	Number of questions
User	The questions in the self-assessment method shall have higher degree of clarity	Understandable questions
User	The self-assessment method shall include web-based, desktop and mobile access	Access/Mobility
User/Developer	The self-assessment method shall be a one-step closed loop process which after completing guarantees that the answers are reported, analyzed and areas where the improvement is necessary are highlighted	Closed-loop process
User/Developer	The self-assessment method shall be a cheap tool/process	Price
User/Developer	The self-assessment method shall be a simple tool/process	Complexity

### 3.3 Conceptual solutions analysis

In this section, concepts will be generated based on the extracted requirements. Then, these concepts will be evaluated and compared to each other. The strong and weak sides of each concept will be identified and discussed. Finally, the best alternative will be chosen based on the analysis and new model will be developed.

#### 3.3.1 Definition of the generated concepts

Generated concepts are:

1. **Software-based survey:** Software tools for surveys are varied, ranging from desktop applications to complex web systems for monitoring consumer behaviour. They enable to create easily useful and attractive questionnaires that are easy to fill out. Integrated number crunching, analyzing the data and generating reports features.
2. **Online web-based survey:** An online web-based survey is the collection of data through a self-administered electronic set of questions on the web. Web-based surveys allow to control the physical appearance and create attractive and inviting forms. Surveys may be created using any kind of device like pc, mobile phone, iPad etc. which is connected to the internet.
3. **Computer program:** A self-assessment computer program may be developed to self-asses the maintenance management system.

Using the relevant criteria identified in Table 2, the following weighting approach applied to each alternative:

*Table 3 The overall weighted value for each alternative*

<b>Context: Model development</b>					
<b>Decision: Choose specific alternative</b>					
<b>Criteria</b>			<b>Alternatives</b>		
<b>Name</b>	<b>Weight</b>	<b>Normalized weight</b>	<b>Software-based survey</b>	<b>Online web-based survey</b>	<b>Computer program</b>
<b>User-friendly</b>	<b>100</b>	<b>0.33</b>	80	90	100
<b>Complexity</b>	<b>90</b>	<b>0.30</b>	90	100	20
<b>Cost</b>	<b>70</b>	<b>0.23</b>	60	90	30
<b>Access/Mobility</b>	<b>40</b>	<b>0.14</b>	90	100	70
<b>Total Score</b>			<b>79.8</b>	<b><u>94.4</u></b>	<b>55.7</b>

In Table 3 we can observe that the scores on each criteria are combined to determine an overall value for each alternative. This determination of an overall value is achieved by calculating the weighted sum of each column in the value payoff matrix. That is, the weighted overall value,  $v_j$ , is computed for each of the  $N_j$  alternatives over the  $N_i$  criteria:  $v_j = \sum_{i=1}^{N_i} w_i v_{ij}$ , where  $w_i$  is the weight of the  $i$ th criteria, and  $v_{ij}$  is the payoff of the  $j$ th alternative for the  $i$ th criteria.

The result of this decision analysis is that the second alternative, namely “online-based survey” is the best alternative as it has the highest calculated score. However, Bratvold & Begg, (2010) state that this approach can cause a problem, because it ignores the payoffs of the alternatives. The criteria should be ranked according to their importance in distinguishing between alternatives, not some absolute measure of importance. This problem can be overcome by using *swing weighting*, which considers the relative magnitudes of the payoffs. The criteria are first ranked by considering two hypothetical alternatives: one consisting of the worst possible payoffs on all criteria (in terms of score, not value), and one consisting of the best possible payoffs. The criteria with the best score that represents the greatest percentage gain over its worst score is given the highest rank, and the methodology is repeated for the remaining criteria until all are ranked.

Table 4 below illustrates the swing ranking process.

Table 4 Swing Ranking

Criteria			Alternatives			
Name	Worst	Best	Swing Rank	Software-based survey	Online-based survey	Computer program
User-friendly	80	100	4	80	90	100
Complexity	20	100	1	90	100	20
Cost	30	90	2	60	90	30
Access/Mobility	70	100	3	90	100	70

Now, the criteria are ranked according to their importance. Table 5 illustrates new ranking using the swing rank:

Table 5 Weighting approach using swing rank

Criteria	Rank	Weight	Normalized
Complexity	1	100	0.33
Cost	2	90	0.30
Access/Mobility	3	70	0.23
User-friendly	4	40	0.14
<b>Sum</b>		300	1.00

Finally, we assess the alternatives against criteria with updated ranks using the same method as described previously. This is illustrated in Table 6.

Table 6 The overall weighted value for each alternative using swing ranks

<b>Context: Model development</b>					
<b>Decision: Choose specific alternative</b>					
<b>Criteria</b>			<b>Alternatives</b>		
<b>Name</b>	<b>Weight</b>	<b>Normalized weight</b>	<b>Software-based survey</b>	<b>Online-based survey</b>	<b>Computer program</b>
<b>Complexity</b>	<b>100</b>	<b>0.33</b>	90	100	20
<b>Cost</b>	<b>90</b>	<b>0.30</b>	60	90	30
<b>Access/Mobility</b>	<b>70</b>	<b>0.23</b>	90	100	70
<b>User-friendly</b>	<b>40</b>	<b>0.14</b>	80	90	100
<b>Total Score</b>			<b>79.6</b>	<b><u>98.6</u></b>	<b>45.7</b>

Again, the second alternative “online-based survey” has the highest score and is our best alternative.

### 3.4 Development analysis of the selected concept

There are many types of online-based survey tools. It is decided that the “Google Forms” will be used as it is free and do not have any limitations on how much questions one can have in the survey and can have any number of polls. It is mobile friendly and can be done with pc, mobile phone, iPad etc. Another advantage of “Google Forms” is that all the votes and responses are automatically collected in an excel spreadsheet and that makes it easier to analyze large sets of data using charts and other complex spreadsheet functions. It also supports a wide range of question types including comments, yes or no questions, scale and grid. These will be illustrated below using snapshots so that the reader gets better understanding of the proposed concept.

#### 3.4.1 Development of the whole self-assessment model

We will now suggest and develop the new self-assessment model based on the selected concept. The flowchart of the developed maintenance self-assessment model is illustrated on the figure 12.

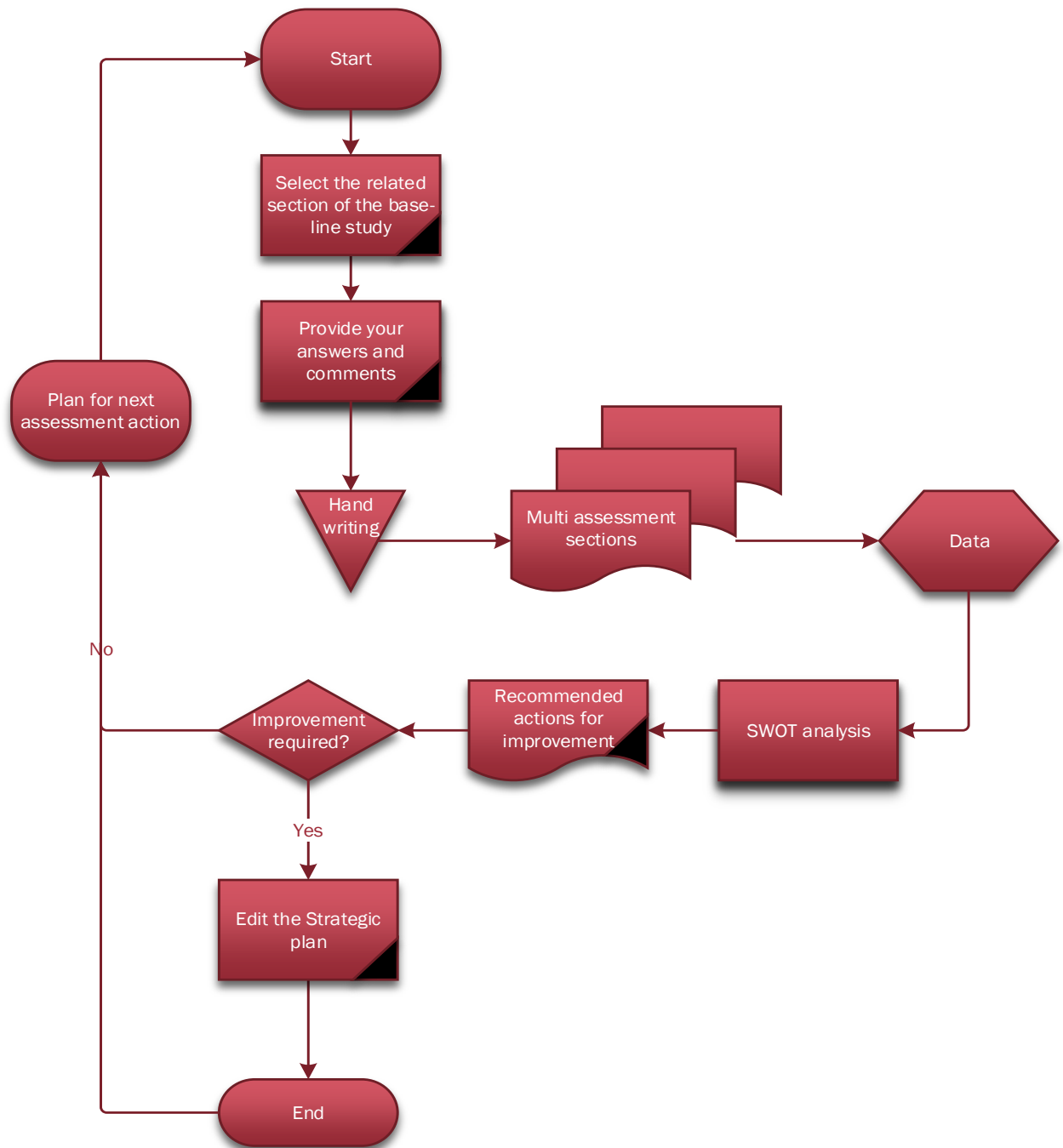


Figure 12 Flowchart of the developed maintenance self-assessment model

1. Select the function of the maintenance management loop to be assessed
2. Go through the questions from the self-assessment method by providing your answers and comments and gather the data
3. Based on the obtained data, perform a SWOT analysis and identify the current status and improvement potential
4. Generate recommended actions for improvement
5. If improvement is required, edit the strategic plan and end the assessment
6. If improvement is not required, plan for the next assessment action

### 3.4.2 Allocations of model requirements

However, in order to enable the above described self-assessment model, several functional requirements shall be physically allocated in the developed model. The most critical functional requirements, that are needed to be allocated, are the following:

- The questioning format of the self-assessment should visualize the logical relations and order of the assessed process.
- The answering style shall offer the selective type rather than just descriptive or limited to yes/no questions.
- The questioning style shall enable us to assess the abilities (internal strength and weaknesses) and capabilities (external opportunities and challenges) of each maintenance operation within the maintenance management loop.
- The questioning style shall enable us to quantify the assessment in order to measure, trend, and compare the results over the time.
- The model shall provide a user-friendly report for the individual assessment
- The model shall provide a user-friendly report for the group assessment e.g. several departments within the same company
- The model shall provide a link between the reported assessment findings and operational and strategic improvement planning tools e.g. SWOT analysis.

However, it is important to highlight that for development purposes, the author has purposefully selected three functions within the maintenance management loop, as shown in figure 13. The experts in O&M hub expressed the high importance of these functions. This purposeful selection also aims to delimit the development work to meet the time limitation.

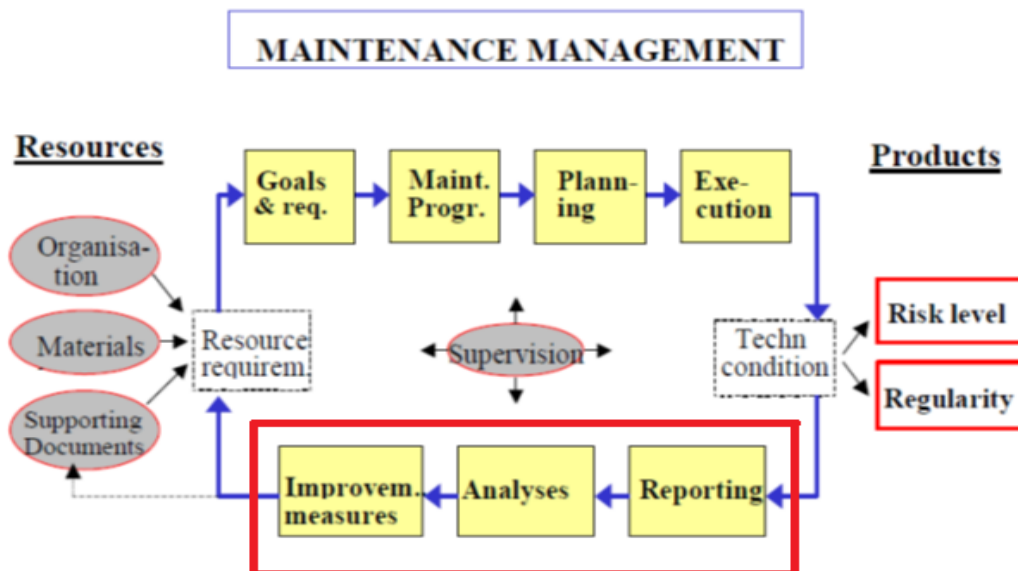


Figure 13 The selected functions for model development (within red box) within the whole Maintenance Management Loop (The Norwegian Petroleum Directorate, 1998)

### 3.4.2.1 Enhancing the questioning format

The questions within the current Maintenance baseline study can be potentially re-organised in order to visualize the internal relations between the question as the series of related questions and the external relations between other questions of other functions (blocks within the Maintenance management loop). It is firstly necessary to identify the processes associated with the selected functions and the abilities which are needed to complete these processes. These are collected in the Table 7 below.

*Table 7 The necessary processes and abilities associated with the selected functions*

<b>Processes</b>	<b>Abilities</b>
Data collection process	Ability to collect the required measures
Analyses process	Ability to perform the required analyses on time
Trending process	Ability to trend the reported measures over the time
Evaluation process	Ability to compare between the reported measures
Reports preparation process	Ability to prepare the reports
Generating effective recommended actions	Ability to provide effective recommended actions
Assessment process	Ability to assess the recommended actions
Prioritizing process of recommended actions	Ability to prioritize the most relevant recommended actions
Illustration process of recommended actions	Ability to illustrate the analyses and the recommended actions
Plan and schedule process of recommended actions	Ability to plan and schedule the improvement process
Distribute and share process of recommended actions	Ability to distribute the final reports
Responsibility management	Responsibility for the whole process

### 3.4.2.2 Change in answering style (from descriptive into selective)

The original version of the self-assessment method developed by NPD consists of many types of questions which can be answered in many ways. These include mostly yes or no and comments. However, in the new survey-based concept developed, there have been included scaling and answer alternatives where appropriate, so that the assessor clicks on the answer alternative which suits the most and do not need to spend much time on trying to answer the question. Of course, it has not been performed a thorough analysis for all the questions to include suitable answer alternatives due to time and expertise limitations. Those which are included are for illustration purpose to show how it would look like.



## Overall, safety-related objectives and management parameters

Has the company a set of clear, safety-related, maintenance objectives (long term, annual)?

- Yes  
 No

If yes, which?

Your answer \_\_\_\_\_

Figure 14 Illustration of the yes or no question type

Which requirements exist for the frequency of monitoring, reporting and analysis of outstanding CM's(weekly, monthly, over time (trends)?

- Weekly  
 Monthly  
 Annual  
 Other

If other, specify which

Your answer \_\_\_\_\_

Figure 15 Illustration of the type of question with multiple choice answer alternatives

## Criticality classification

Which requirements does the company have as regards conducting analyses (functional analyses,FMEA/FMECA, etc.) for establishing criticality of systems and equipment?

- Criticality analysis using qualitative techniques  
 Criticality analysis using risk assessment techniques  
 Criticality analysis using analytical hierarchy process (AHP)  
 Other

If other, specify which?

Your answer \_\_\_\_\_

Figure 16 Illustration of the type of question with checkbox answer alternatives

### Work permits

Are there clear requirements relating to obtaining work permits?

- Yes  
 No

Are these complied with?

- Yes  
 No

Is the process efficient: To what degree does it "guarantee" a safe work place?

	1	2	3	4	5	
Not very effective	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Very effective

Who (position) approves the work permits?

Your answer

Figure 17 Illustration of the type of question with linear scaling answer alternative

As the reader can observe from the figures above, this way of performing a self-assessment of maintenance management system is much easier and requires less effort and time to conduct. It also reports the answers at the same time as the self-assessment is conducted. There is no need for excessive writing, documenting and reporting of the results as everything is done in one step which makes it more user-friendly and easy to handle.

However, the questions within the developed model have taken clearly the selective format with open space for descriptive answers as well as shown in figure 18.

...

3. Please select the challenging aspect(s) of data collection process

- Clarity of the measures
- High operational changes lead to changes in the collected data
- Lack of clear guidelines for which measuring parameters have the highest priority
- Lack of available resources in the form of skills, time, methods and equipment
- Lack of a robust data collection process
- Ineffective or non-existent data monitoring and review process
- Other...

Figure 18 From descriptive into selective type of question

### 2.4.2.3 Explore the opportunities and challenges

The new maintenance self-assessment model of the selected functions will be based on these identified processes and the associated abilities to complete them. For example, if we want to assess the data collection process, we need to assess if the department's ability to collect the required measure(s) to be reported is sufficient. In addition, we need to know if the data collection process is challenging and what are the challenges associated with this process. Using this approach, all the functions with their associated processes and necessary abilities to complete the processes are assessed. The answers are quantified and challenges are identified. In addition, some control questions are provided to assess the selected functions.

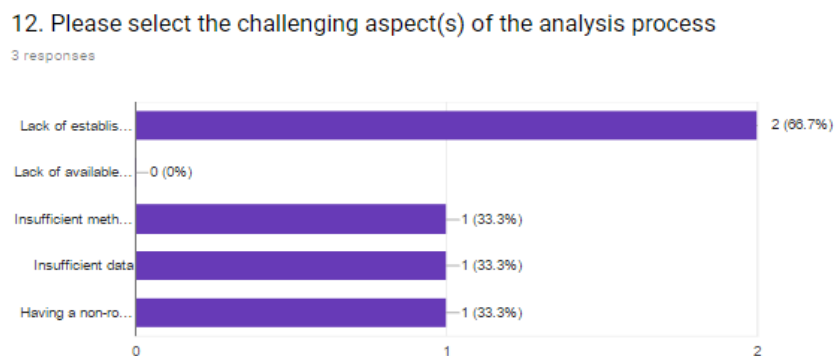


Figure 19 Illustration of challenging aspects

### 3.4.2.4 Use semi-quantitative response (levels)

To quantify the assessment of the different abilities (internal strength and weaknesses) and capabilities (external opportunities and challenges) where the assessor can choose between multiple alternatives, the following approach will be utilized:

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other (specify)

1. Do you find your department's ability to collect the required measure(s) to be reported as quite sufficient? \*

Always (more than 80% of the cases)

Often (more than 60% of the cases)

Sometimes (more than 40% of the cases)

Rarely (more than 20 % of the cases)

Never (less than 20% of the cases)

Other: \_\_\_\_\_

Figure 20 Quantifying the answers

Figure 21 shows how the responses have been collected and presented within the developed model.

18. Do you find your department's ability to trend the reported measures over the time is quite sufficient?

3 responses

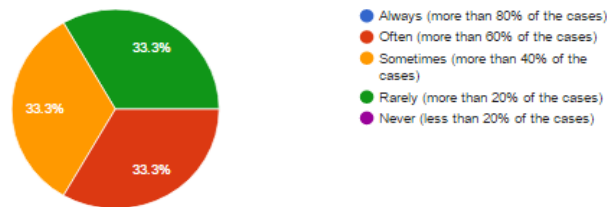


Figure 21 Semi-quantitative response

### 3.4.2.5 Effective illustration of individual responses

When the self-assessment of the maintenance management system is completed, it is possible to see the responses in four ways:

1. View responses by question (summary). The summary of responses will include graphs depicting the spread of responses. Answers to text/paragraph questions will be shown. You cannot manipulate the data in any way from this view. You will have to head over to Sheets to do that.

Is the process efficient: To what degree does it "guarantee" a safe work place?

(1 response)

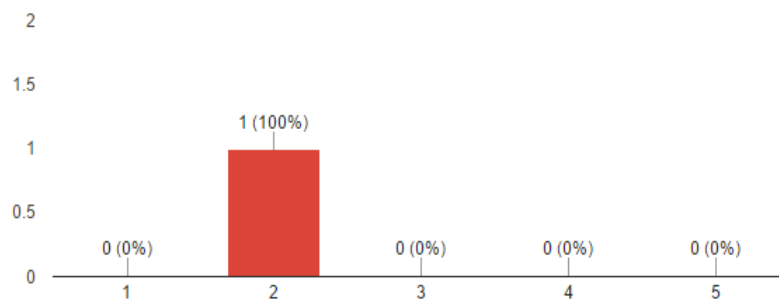


Figure 22 Responses by question 1

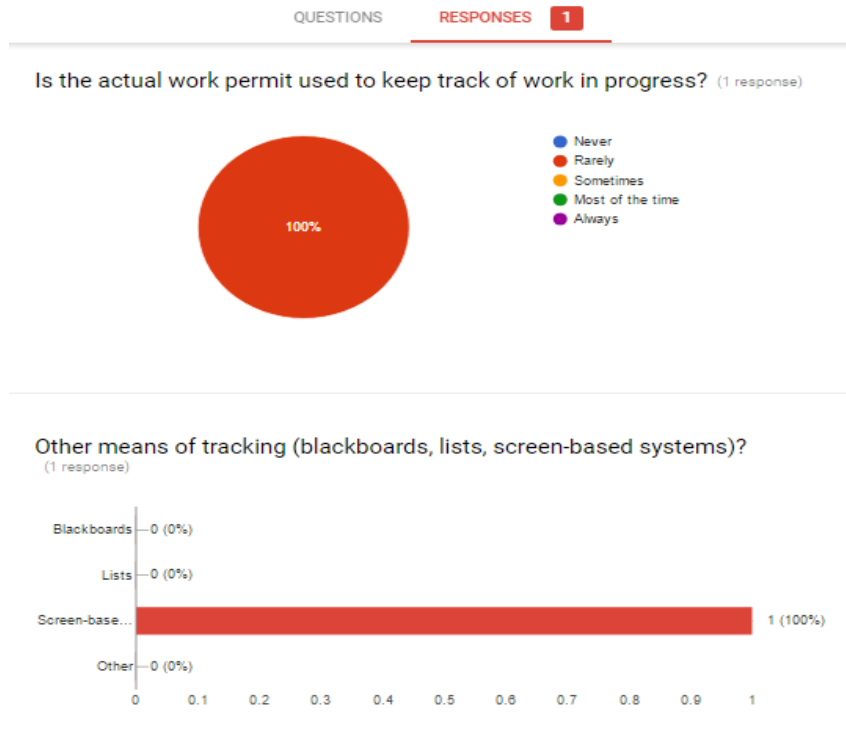


Figure 23 Responses by question 2

## 2. View responses by person (individual)

QUESTIONS    **RESPONSES** 1

---

Are there clear rules for marking and/or isolating equipment which is shut down and/or which is under repair?

1      2      3      4      5

Very poor                        Very good

Both for brief periods and over long periods?

For brief periods

Over long periods

Both for brief periods and over long periods

Is the marking clearly visible/distinctive?

Yes

No

How does the operating personnel keep informed of equipment which is out of operation?

This is an example..

Figure 24 Responses by person 1

QUESTIONS    **RESPONSES** 1

---

This is an example..

**Is the actual work permit used to keep track of work in progress?**

Never  
 Rarely  
 Sometimes  
 Most of the time  
 Always

**Other means of tracking (blackboards, lists, screen-based systems)?**

Blackboards  
 Lists  
 Screen-based systems  
 Other

**If other, specify which?**

*Figure 25 Responses by person 2*

### 3. View all responses in a spreadsheet

Timestamp	GN	GO	GP	GG	GR	GS	GT	GU	GV	GW	GX	GY
1	Is the technical work con... Is this done on a spot ch... If other, specify which? How is inexperienced per... If other, specify how? Are checks being made... Are check-lists used to e... Have clear rules been es... Have requirements been... Is the need for, and moti... What are the ben...											
2		2	4	On a spot check basis		Interview, Evaluation, Training		2	3	Yes	Yes	5
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												

*Figure 26 All responses on a spreadsheet*

4. Download all responses in a CSV file, which is a simple file format used to store tabular data, such as a spreadsheet or database. Files in the CSV format can be imported to and exported from programs that store data in tables, such as Microsoft Excel or OpenOffice Calc.

After the assessor has completed the maintenance management self-assessment, he or she can obtain user-friendly individual assessment.

3. Please select the challenging aspect(s) of data collection process

- Clarity of the measures
- High operational changes lead to changes in the collected data
- Lack of clear guidelines for which measuring parameters have the highest priority
- Lack of available resources in the form of skills, time, methods and equipment
- Lack of a robust data collection process
- Ineffective or non-existent data monitoring and review process
- Other: .....

Figure 27 Individual assessment 1

1. Do you find your department's ability to collect the required measure(s) to be reported is quite sufficient? \*

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20 % of the cases)
- Never (less than 20% of the cases)
- Other: .....

Figure 28 Individual assessment 2

**3.4.2.6 Effective illustration for group/shared assessment (cross-department and / or cross-companies)**

The assessor can also obtain a user-friendly group assessment. The group assessment can then be used by different managers in several departments within the company, or cross-companies.

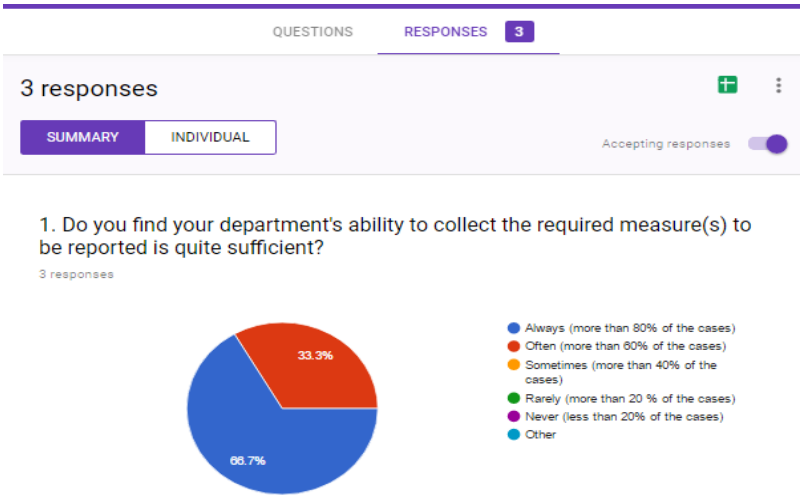


Figure 29 Group assessment 1

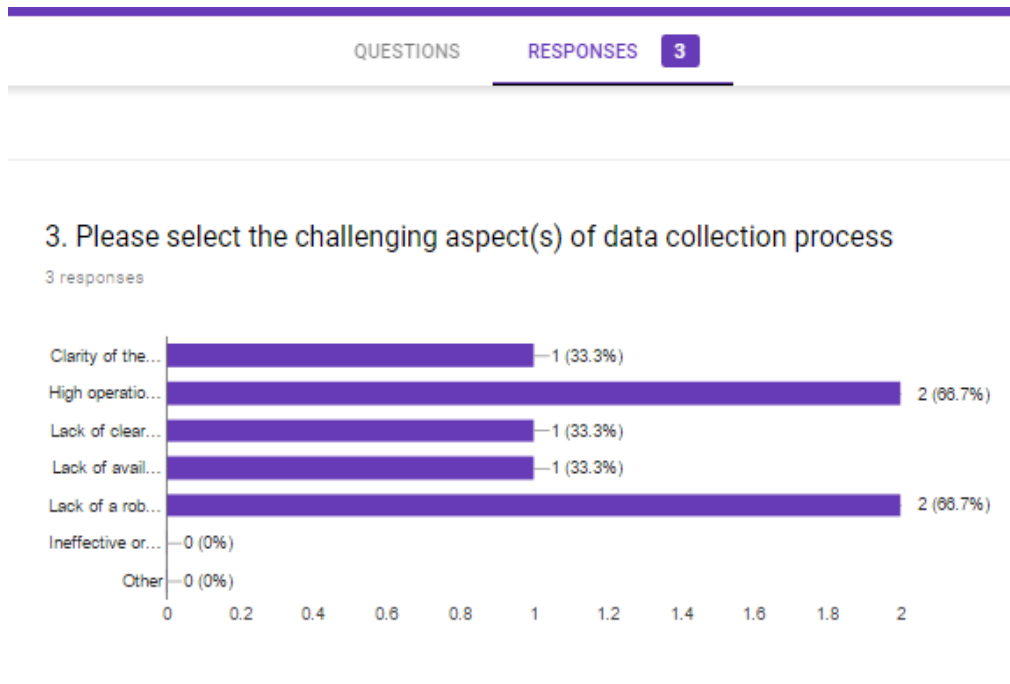


Figure 30 Group assessment 2

### 3.4.2.7 Linking the assessment into SWOT analysis

Linking the SWOT analysis to self-assessment method will help us to evaluate the maintenance management system as it will allow us to identify internal and external factors that are favourable and unfavourable. It is a simple analysis method because it requires neither technical skills nor training, and can be performed by anyone with knowledge about the maintenance management system. It is also a cheap method as it does not require technical skills or training, and a company can select a staff member to conduct the analysis rather than hire an external consultant. In addition, a SWOT analysis requires less time to conduct compared to other complex analysis methods. Using a SWOT analysis, we can:

- Understand our maintenance management system better
- Address weaknesses
- Deter threats
- Identify opportunities
- Take advantage of our strengths
- Develop goals and strategies

The process of linking the assessment to SWOT analysis will be illustrated and explained below.



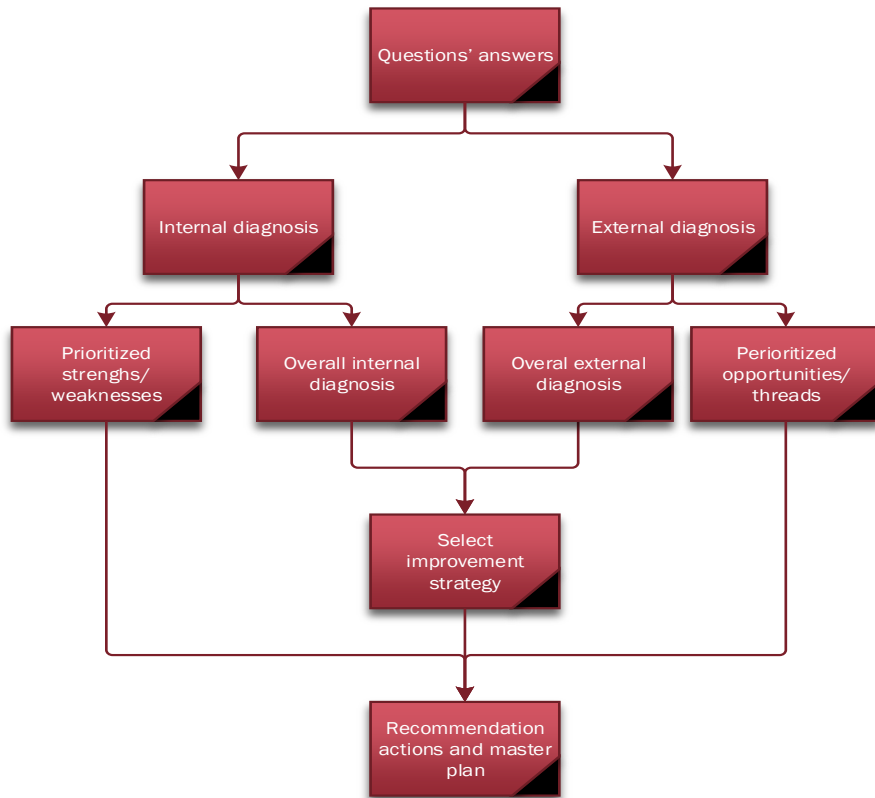


Figure 31 Flowchart of self-assessment and associated improvement strategic plan

Quantitative answers to questions related to department's abilities will tell us about internal strengths and weaknesses, while quantitative answers to questions related to processes associated to the selected functions will tell us about external opportunities and threats.

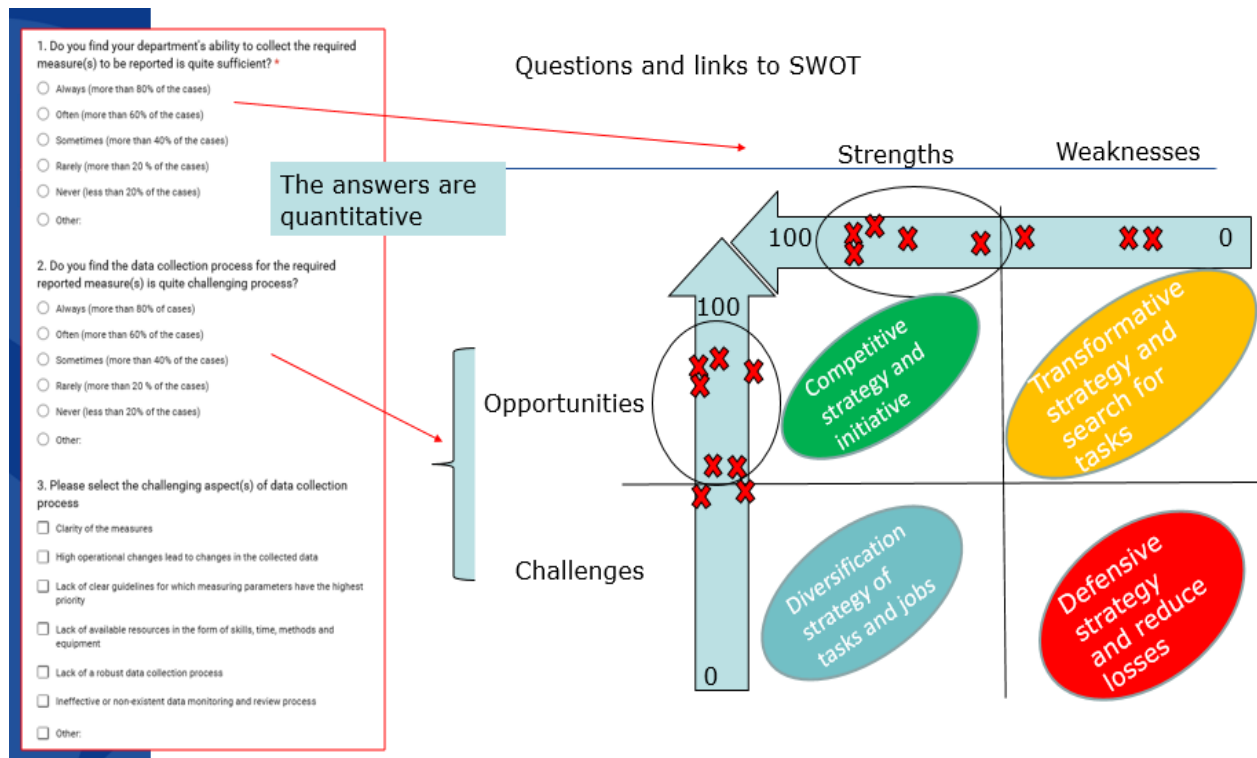


Figure 32 Questions and links to SWOT analysis

To visualize the assessment of the selected maintenance management functions in a more informative and user-friendly way, we need to collect the quantitative answers in the table and then plot them into a spider diagram.

Table 8 Required abilities

Answers related to abilities	Value	Strength line	Weakness line
1. Data collection	80	100	49
4. Data analysis	60	100	49
7. Trending analysis	60	100	49
10. Evaluation analysis	60	100	49
15. Effective recommended actions	40	100	49
18. Recommended actions assessment	40	100	49
21. Prioritization	60	100	49
24. Recommended actions illustration	20	100	49
27. Plan and schedule the improvement process	80	100	49
30. Reports distribution and sharing	60	100	49
33. Responsibility	20	100	49

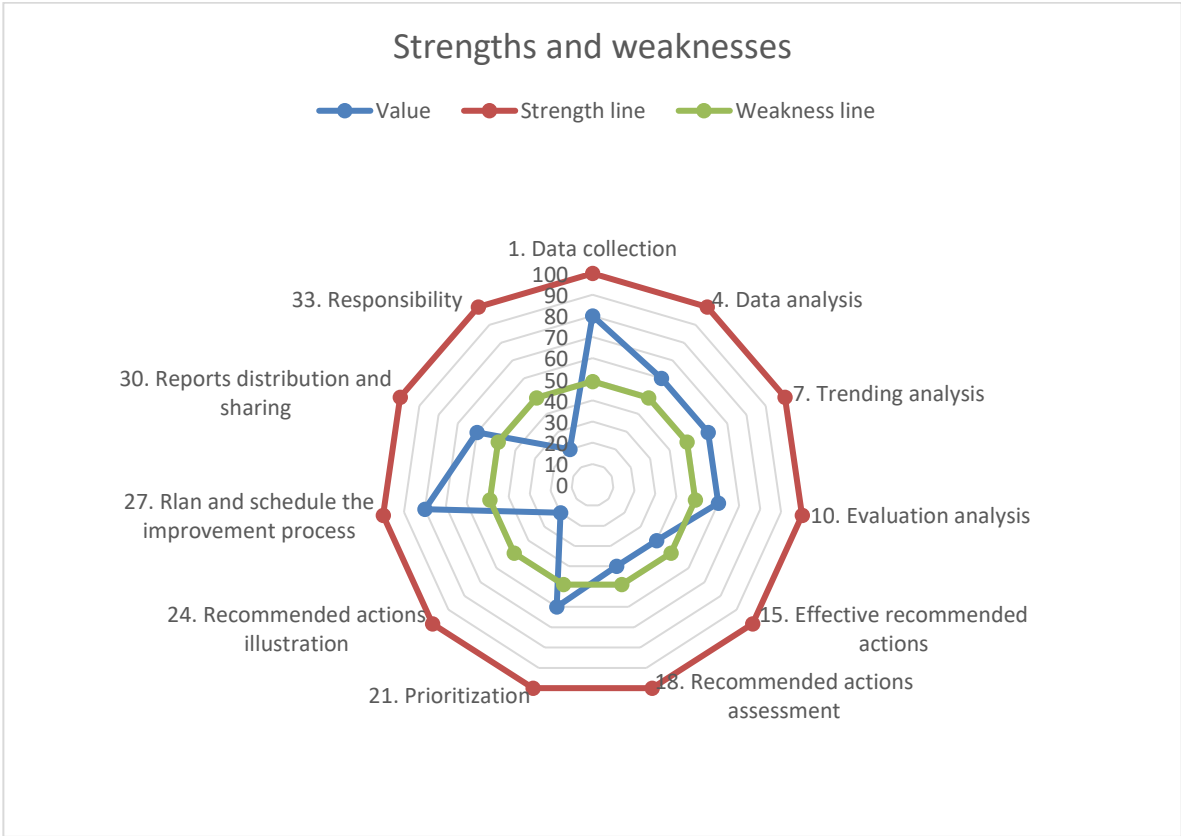


Figure 33 Spider diagram illustrating the self-assessment results related to abilities

Tabell 9 Required processes

Answers related to processes	Value	Opportunity line	Threat line
2. Data collection process	60	100	49
5. Analysis process	80	100	49
8. Trending process	60	100	49
11. Evaluation process	40	100	49
13. Reports preparation process	80	100	49
16. Generating effective recommended actions	80	100	49
19. Assessment process	80	100	49
22. Prioritizing process of recommended actions	20	100	49
25. Illustrate process of recommended actions	60	100	49
28. Plan and schedule process of the recommended actions	20	100	49
31. Distribute and share process of the final reports	20	100	49
34. Responsibility management	60	100	49

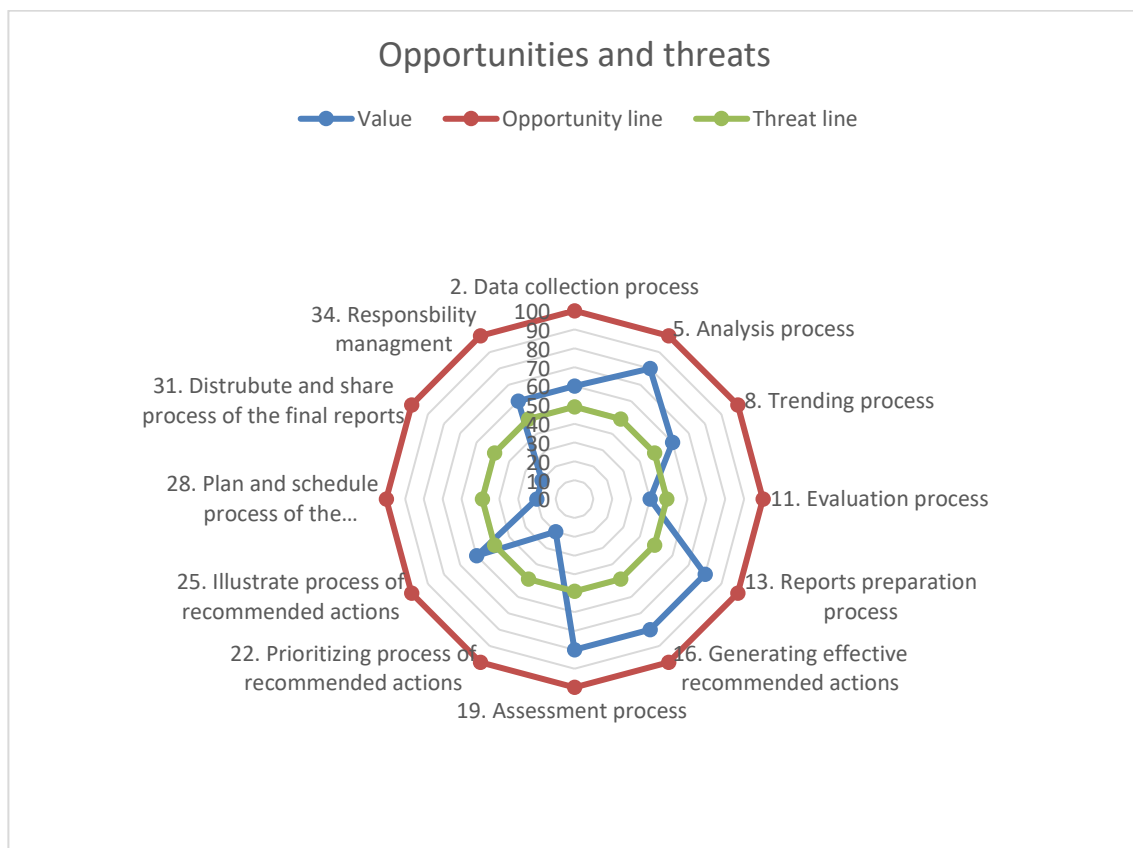


Figure 34 Spider diagram illustrating the self-assessment results related to processes

### 3.5 Verification and validation analysis

In order to verify and validate the new self-assessment method, a sample survey of the new self-assessment method that has been developed using google forms. Three functions of the maintenance management loop, namely reporting, analysis and improvement measures has been selected for that purpose. A PowerPoint presentation describing the new self-assessment tool and how it is intended to work has also been prepared. In addition, another survey containing nine questions related to the new self-assessment tool has also been created in order to assess the developed model. This assessment survey containing nine questions can be seen below.

*Table 10 Assessment survey of the developed self-assessment tool*

<p>1. Do you agree that the new survey based self-assessment method is less time consuming compared to original method? Mark only one oval.</p> <p><input type="radio"/> Strongly agree</p> <p><input type="radio"/> Agree</p> <p><input type="radio"/> Neither agree or disagree</p> <p><input type="radio"/> Disagree</p> <p><input type="radio"/> Strongly disagree</p> <p>2. Do you agree that the questions in the new self-assessment method are clear and easy to understand?</p> <p>Mark only one oval.</p> <p><input type="radio"/> Strongly agree</p> <p><input type="radio"/> Agree</p> <p><input type="radio"/> Neither agree or disagree</p> <p><input type="radio"/> Disagree</p> <p><input type="radio"/> Strongly disagree</p> <p>3. Do you agree that the questions in the new self-assessment method are relevant? Mark only one oval.</p> <p><input type="radio"/> Strongly agree</p> <p><input type="radio"/> Agree</p> <p><input type="radio"/> Neither agree or disagree</p> <p><input type="radio"/> Disagree</p> <p><input type="radio"/> Strongly disagree</p>
---

4. Do you agree that the questions in the new self-assessment method cover all the necessary areas for the selected maintenance management functions to be assessed? Mark only one oval.

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

5. Do you agree that the new self-assessment method is user-friendly and easy to use? Mark only one oval.

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

6. Do you agree that there is an advantage in moving from descriptive (yes/no) questions into selective type of questions where the answers can be quantified? Mark only one oval.

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

7. Do you agree that the analysis approach of linking the assessment into an SWOT analysis is relevant? Mark only one oval.

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

8. Do you agree that the illustration approach of the assessment analysis is relevant? Mark only one oval.

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

9. Do you have any other comments related to the new self-assessment method?

This survey and the presentation file of the developed self-assessment tool was sent to purposefully selected experts in the field of maintenance management within the oil and gas industry. The aim was to help us to analyze the effectiveness of the developed self-assessment tool and provide a feedback for further development. The evaluations of the assessment survey are illustrated for each in the following figures 35, 36, 37, 38, 39, 40, 41, 42.

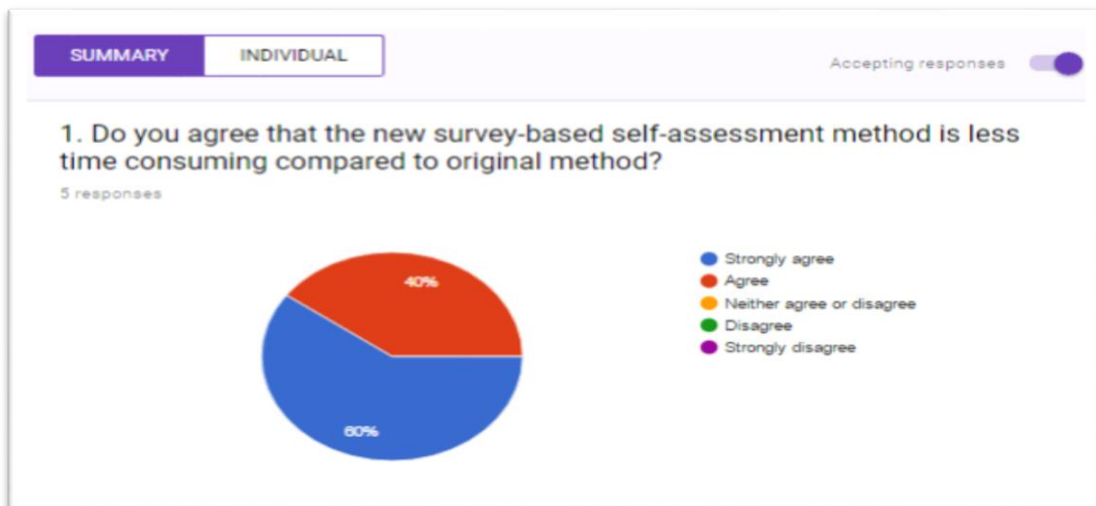


Figure 35 Evaluation of the assessment 1

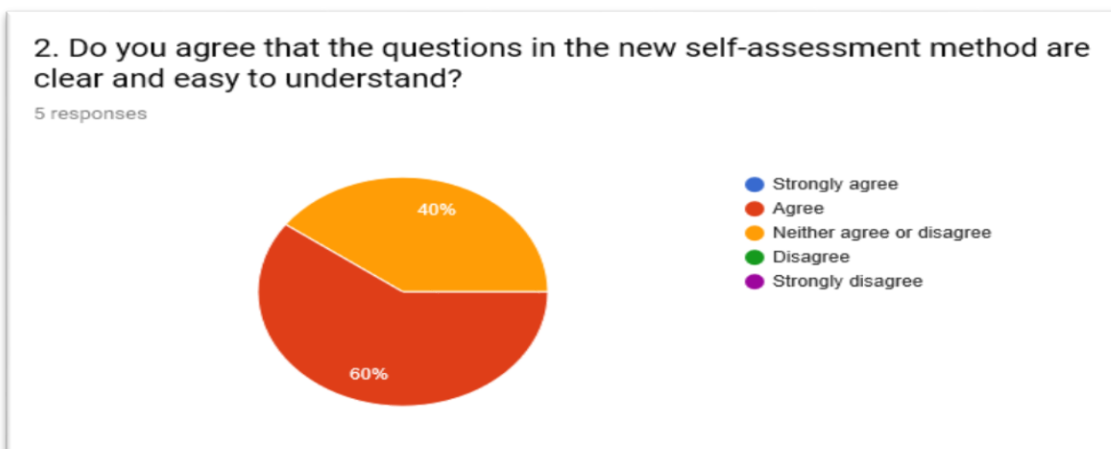


Figure 36 Evaluation of the assessment 2

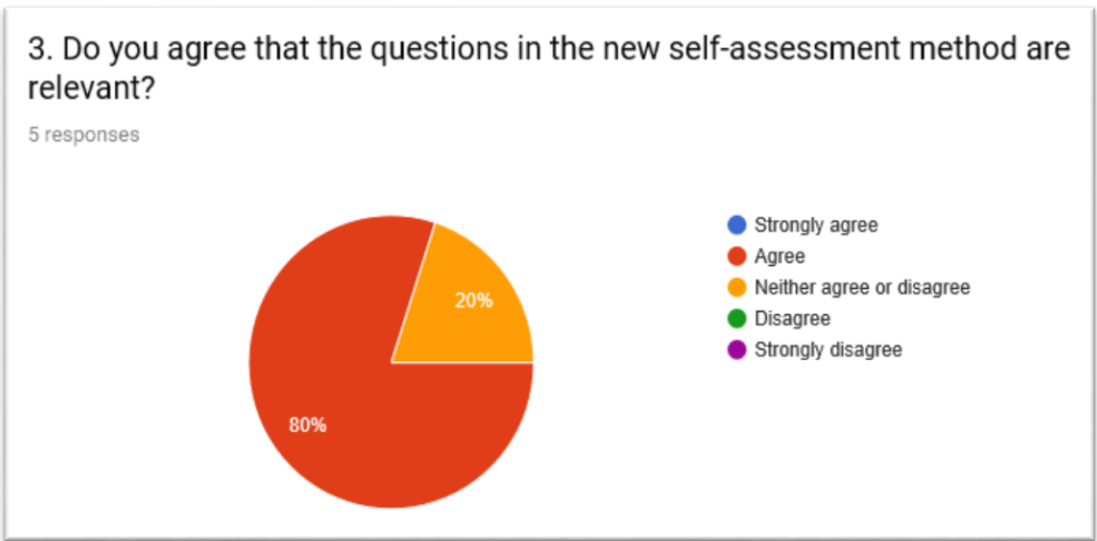


Figure 37 Evaluation of the assessment 3

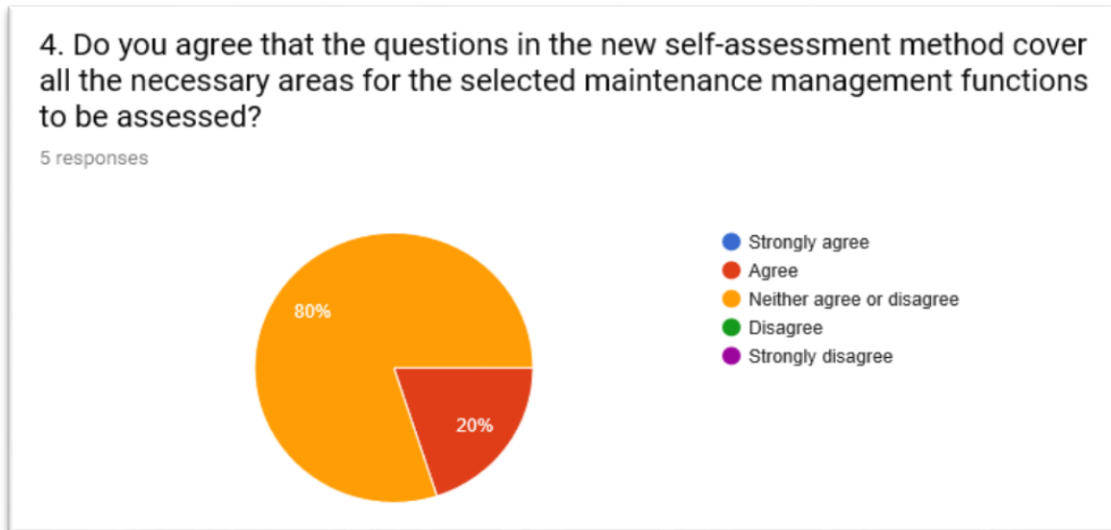


Figure 38 Evaluation of the assessment 4

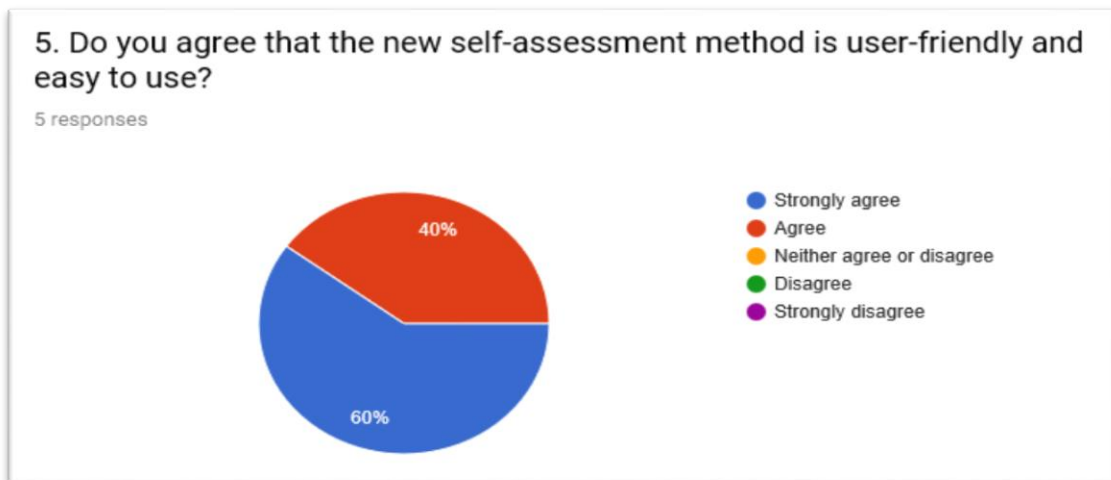


Figure 39 Evaluation of the assessment 5

6. Do you agree that there is an advantage in moving from descriptive (yes/no) questions into selective type of questions where the answers can be quantified?

5 responses

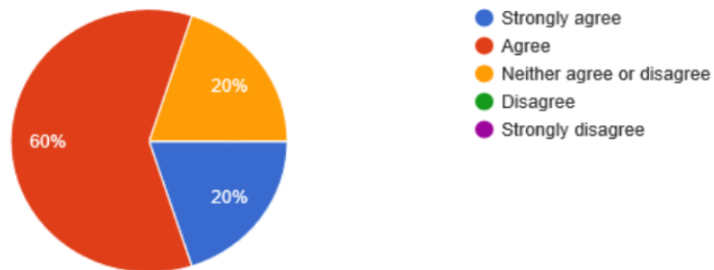


Figure 40 Evaluation of the assessment 6

7. Do you agree that the analysis approach of linking the assessment into an SWOT analysis is relevant?

5 responses

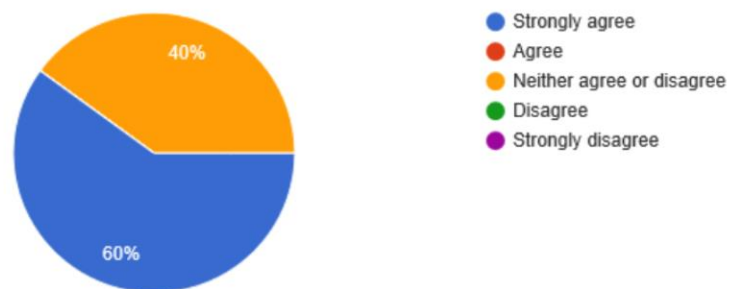


Figure 41 Evaluation of the assessment 7

8. Do you agree that the illustration approach of the assessment analysis is relevant?

5 responses

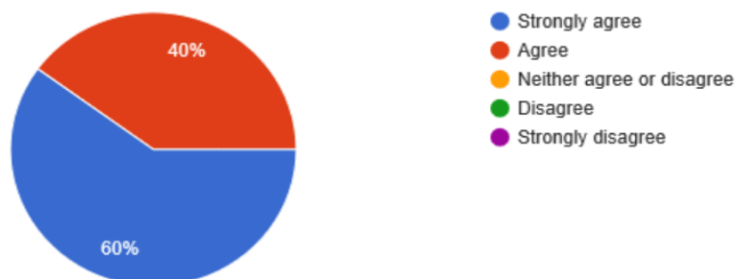


Figure 42 Evaluation of the assessment 8



Then, interviews with the professionals in the field of maintenance management has been planned and conducted face to face. The results from the interviews and surveys are presented in the table 11.

*Table 11 Results from the interviews*

<b>Statements</b>	<b>Answers</b>
New self-assessment tool is less time consuming compared to original version	Agree
The questions in the new self-assessment method are clear and easy to understand	Neither agree or disagree
The questions in the new self-assessment method are relevant	Agree
The questions in the new self-assessment method cover all the necessary areas for the selected maintenance management functions to be assessed	Neither agree or disagree
The new self-assessment method is user-friendly and easy to use	Strongly agree
There is an advantage in moving from descriptive (yes/no) questions into selective type of questions where the answers can be quantified	Neither agree or disagree
The analysis approach of linking the assessment into a SWOT analysis is relevant	Neither agree or disagree
The illustration approach of the assessment analysis is relevant	Strongly agree

As we have discussed earlier, the current maintenance self-assessment method is time-consuming, not user-friendly and has no integrated ability to analyze and illustrate the answers. The surveys and interviews confirm that the new self-assessment tool is much more user-friendly and easy to use, less time-consuming and has an effective illustration approach compared to the original version of the self-assessment method.

However, these interviews and surveys also indicate first that the questions in the new self-assessment tool are not so clear and easy to understand. In fact, the author has just used the same questions of the original maintenance baseline study and converted them into selective form. Therefore, it can be concluded that the question in both the original maintenance baseline study and the selective form that have been used in the developed self-assessment tool shall be clear and relevant questions that can be easily understood by those who will use the self-assessment tool.

Second feedback from the experts is that the questions should also cover all the necessary areas for the selected maintenance management functions to be assessed in order to have an efficient self-assessment of maintenance management system. It is also not so clear if it is an advantage in moving from descriptive (yes/no) questions into selective type of questions where the answers can be quantified. The professionals in the field of maintenance management suggest that quantitative and qualitative approaches should be combined, so that for example interviews may be structured and analyzed using quantitative approach by collecting the numeric data, or by categorizing non-numeric answers and coding them in numeric form. Also, survey may be designed so that they allow for open-ended responses and can lead to the in-depth study. In this way, a combination of qualitative and quantitative approaches can provide a more general picture.

The third issue related to the new self-assessment tool is that professionals are doubting if the analysis approach of linking the assessment into a SWOT analysis is relevant. The reason for this may be related to the need of see an actual example of such an analysis and not just demonstration, in order to see the advantage of this improvement measure. However, the general view is that the new self-assessment tool is a good starting point. Companies willing to apply this self-assessment tool will probably have to run it through some customization and adaptation rounds, which is perfectly fine.

In fact, the maintenance baseline study is well known as maintenance management loop within the oil & gas industry. This maintenance management loop is developed in 1998 and the maintenance concepts, approaches and operations have evolved over the last two decades. This means that there is a need to update the maintenance management loop by updating its link to the whole asset management loop e.g. PAS 55 standards and life cycle loop e.g. ISO 55001. In addition, the internal processes of each function within the management loop that is presented in maintenance baseline study of NPD need also to be updated. For example, managers mean that reporting is very crucial and the reporting system need to be standardized so that it has standard definitions allowing for common understanding. Another challenge is utilization of relevant data from the field measurements – sensor technology. There is a data overflow and questions that must be considered are:

- How to handle the data overflow?
- How to capture the most relevant data?
- How to implement actions based on the relevant data?

Lastly, the tools and technologies that can be more cost effective to perform those functions should also be updated.

## 4. Model Demonstration

As described early, the developed model for self-assessment of maintenance management is based on the flowchart in figure 12 and 43.

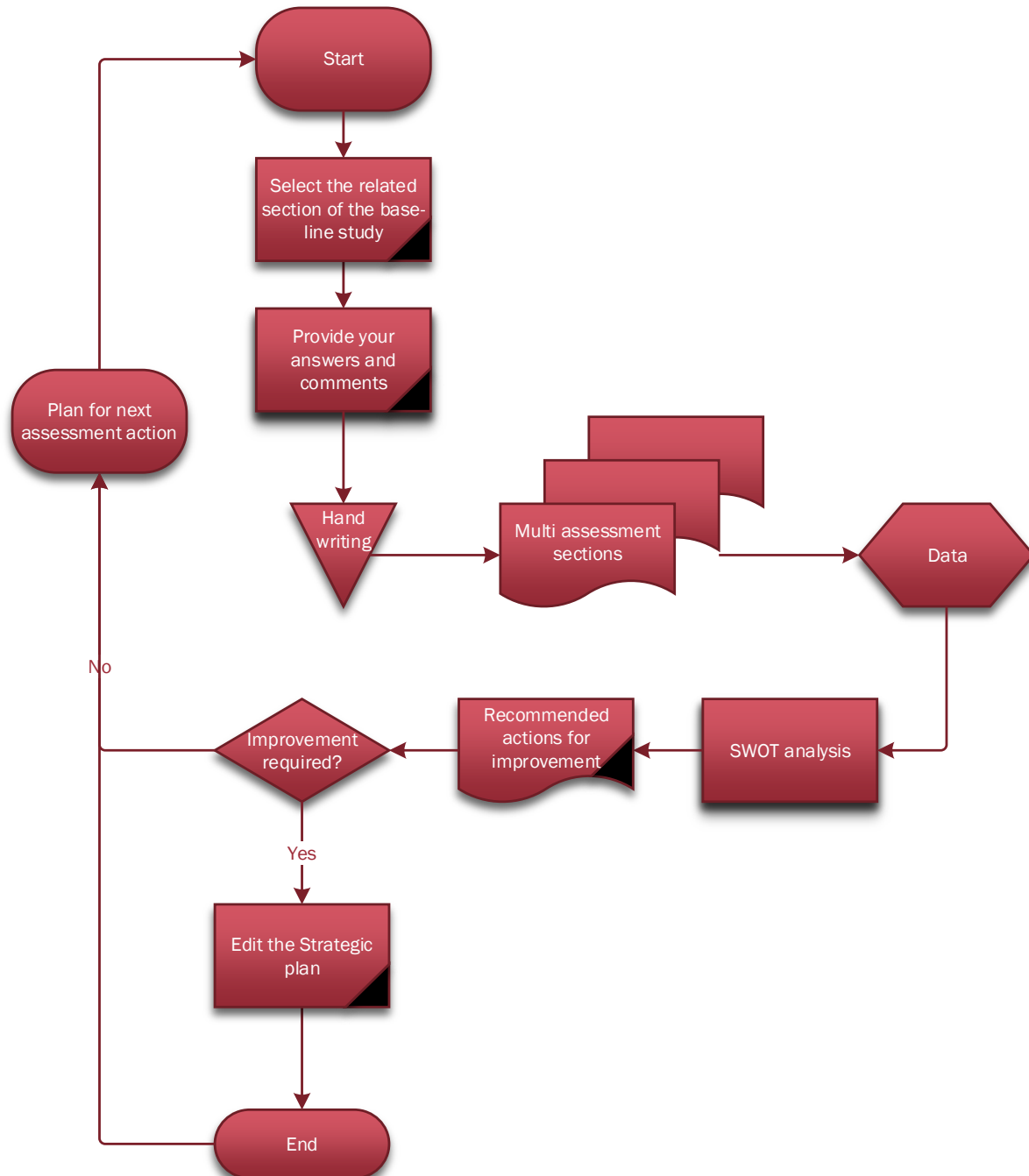


Figure 43 Flowchart of the developed maintenance self-assessment model

1. Select the function of the maintenance management loop to be assessed
2. Go through the questions from the self-assessment method by providing your answers and comments and gather the data
3. Based on the obtained data, perform a SWOT analysis and identify the current status and improvement potential

4. Generate recommended actions for improvement
5. If improvement is required, edit the strategic plan and end the assessment
6. If improvement is not required, plan for the next assessment action

Therefore, it is expected from the use to follow the following steps:

Step 1: Access the online-survey and answer the provided questions as show in figure xxx.

**Self-assessment of Maintenance Management System**

Reporting, Analysis and Improvement Measures

**\*Required**

1. Do you find your department's ability to collect the required measure(s) to be reported is quite sufficient? \*

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20 % of the cases)
- Never (less than 20% of the cases)
- Other:

2. Do you find the data collection process for the required reported measure(s) is quite challenging process?

- Always (more than 80% of cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20 % of the cases)
- Never (less than 20% of the cases)
- Other:

3. Please select the challenging aspect(s) of data collection process

- Clarity of the measures
- High operational changes lead to changes in the collected data
- Lack of clear guidelines for which measuring parameters have the highest priority
- Lack of available resources in the form of skills, time, methods and equipment
- Lack of a robust data collection process
- Ineffective or non-existent data monitoring and review process
- Other: \_\_\_\_\_

*Figure 44 Question sample of the developed model*

However, the whole question sample (46 questions) of the new self-assessment tool is presented in Table 12.

1. Do you find your department's ability to collect the required measure(s) to be reported as quite sufficient? \* Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20 % of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

2. Do you find the data collection process for the required reported measure(s) as quite challenging process? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20 % of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

3. Please select the challenging aspect(s) of data collection process Check all that apply.

- Clarity of the measures
- High operational changes lead to changes in the collected data
- Lack of clear guidelines for which measuring parameters have the highest priority
- Lack of available resources in the form of skills, time, methods and equipment
- Lack of a robust data collection process
- Ineffective or non-existent data monitoring and review process
- Other: \_\_\_\_\_

4. Do the reports provide standard definitions? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

5. Do the reports provide feedback after job execution? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

6. Do the reports provide condition reporting for preventive maintenance tasks? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

7. Do the reports indicate the needs for further analysis for (planning, KPIs, cost, spares, tools etc.)?

Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

8. Do the reports provide inputs for design/modifications? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

9. Do the reports provide feedback into designer/manufacturer/service providers? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

10. Do you find your department's ability to perform the required analysis on time as quite sufficient? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

11. Do you find the analysis process for the required reported measure(s) as quite challenging process? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

12. Please select the challenging aspect(s) of the analysis process Check all that apply.

- Lack of established requirements to initiate analyses when the control parameters indicate nonconformance with company objectives and requirements
- Lack of available resources in the form of skills, time, methods and analysis tools
- Insufficient methods for conducting root cause analyses
- Insufficient data
- Having a non-robust analyses process
- Other: \_\_\_\_\_

13. Do the analysis process provide program review? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

14. Do the analysis process provide back tracking - operational support/analysis?

Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

15. Do the analysis process provide design feedback/integrity performance? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

16. Do the analysis process provide cost benefit analysis? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_



17. Do the analysis process provide inputs to new standard? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

18. Do you find your department's ability to trend the reported measures over the time as quite sufficient? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

19. Do you find the trending process for the required reported measure(s) as quite challenging process?

Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

20. Please select the challenging aspect(s) of the trending process Check all that apply.

- Lack of available resources in the form of skills, time, methods and trending techniques
- Insufficient data
- Inconsistent data quality
- Inefficient trending process
- Other \_\_\_\_\_

21. Do you find your department's ability to compare between the reported measures at different time intervals as quite sufficient? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

22. Do you find the comparison process for the required reported measure(s) as quite challenging process? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

23. Please select the challenging aspect(s) of the comparison process Check all that apply.

- Lack of available resources in the form of skills, time, methods and techniques
- Ineffective or non-existent comparison process
- Lack of available reported measures at different time intervals
- Other: \_\_\_\_\_

24. Do you find the reports preparation process as quite challenging process? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

25. Please select the challenging aspect(s) of report preparation process Check all that apply.

- Availability of data sources
- Clarity and usability of the collected data, it is time consuming to clean up the data
- Inefficient report preparation process
- Lack of available resources in the form of skills, time and methods
- Other: \_\_\_\_\_

26. Do you find your department's ability to provide effective recommended actions based on the analysed reported measures as quite sufficient? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

27. Do you find the process to generate effective recommended actions as quite challenging process?

Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

28 Please select the challenging aspect(s) of generating effective recommended action Check all that apply.

- Inefficient process of generating effective recommended actions
- Lack of available resources in the form of skills, time, methods and techniques
- Changing requirements
- Other: \_\_\_\_\_

29. Do you find your department's ability to assess the recommended actions as quite sufficient?

Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

30. Do you find the assessment process of several recommended actions as quite challenging process?

Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

31. Please select the challenging aspect(s) of the assessment process of recommended actions

Check all that apply.

- Inefficient assessment process
- Lack of available resources in the form of skills, time, methods and techniques
- Other: \_\_\_\_\_

32. Do you find your department's ability to define/prioritize the most relevant recommended actions as quite sufficient? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

33. Do you find the process to define and prioritize the most relevant recommended actions as quite challenging process? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

34. Please select the challenging aspect(s) of the process of defining and prioritizing the most relevant recommended actions Check all that apply.

- Inefficient process of defining and prioritizing the most relevant recommended actions
- Lack of available resources in the form of skills, time, methods and techniques
- Lack of understanding about which areas should be prioritized
- Lack of understanding about which safety-related maintenance parameters should be improved
- Other: \_\_\_\_\_

35. Do you find your department's ability to illustrate the analyses and the recommended actions as quite sufficient? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

36. Do you find the process to illustrate the analyses and the recommended actions as quite challenging process? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

37. Please select the challenging aspect(s) of the process of illustration the analyses and the recommended actions

Check all that apply.

- Lack of available resources in the form of skills, time, methods and techniques
- Other: \_\_\_\_\_

38. Do you find your department's ability to plan and schedule the improvement process related to the most relevant recommended actions as quite sufficient? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

39. Do you find the process to plan and schedule the recommended actions as quite challenging process?

Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

40. Please select the challenging aspect(s) of the process of planning and scheduling the recommended actions Mark only one oval.

- Lack of available resources in the form of skills, time, methods and techniques
- Other: \_\_\_\_\_

41. Do you find your department's ability to distribute the final reports as quite sufficient? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

42. Do you find the process to distribute and share the final reports as quite challenging process? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

43. Please select the challenging aspect(s) of the process to distribute and share the final reports Check all that apply.

- Lack of available resources in the form of skills, time, methods and techniques
- Lack of understanding about which reports the different players/management require
- Other: \_\_\_\_\_

44. Do you find your department's responsibility for the whole process (reporting, analysis and improvement management) as quite sufficient? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

45. Do you find the responsibility management of such process as quite challenging issue? Mark only one oval.

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)
- Other: \_\_\_\_\_

46. Please select the challenging aspect(s) of the responsibility management Check all that apply.

- Lack of clarity about who is responsible for the process
- Lack of available resources in the form of skills, time, methods and techniques
- Other: \_\_\_\_\_

Step 2: Check the personal response in the online-survey tool as show in figure 43.

Responses cannot be edited

SUMMARY INDIVIDUAL Accepting responses

< 1 of 3 >

### Self-assessment of Maintenance Management System

Reporting, Analysis and Improvement Measures

\*Required

1. Do you find your department's ability to collect the required measure(s) to be reported is quite sufficient? \*

- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20 % of the cases)
- Never (less than 20% of the cases)
- Other: .....

2. Do you find the data collection process for the required reported measure(s) is quite challenging process?

- Always (more than 80% of cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20 % of the cases)
- Never (less than 20% of the cases)
- Other: .....

3. Please select the challenging aspect(s) of data collection process

- Clarity of the measures
- High operational changes lead to changes in the collected data
- Lack of clear guidelines for which measuring parameters have the highest priority
- Lack of available resources in the form of skills, time, methods and equipment
- Lack of a robust data collection process
- Ineffective or non-existent data monitoring and review process
- Other: .....

Figure 45 User-friendly report for the individual response



Step 3: Check the summary response in the online-survey tool as show in figure 46.

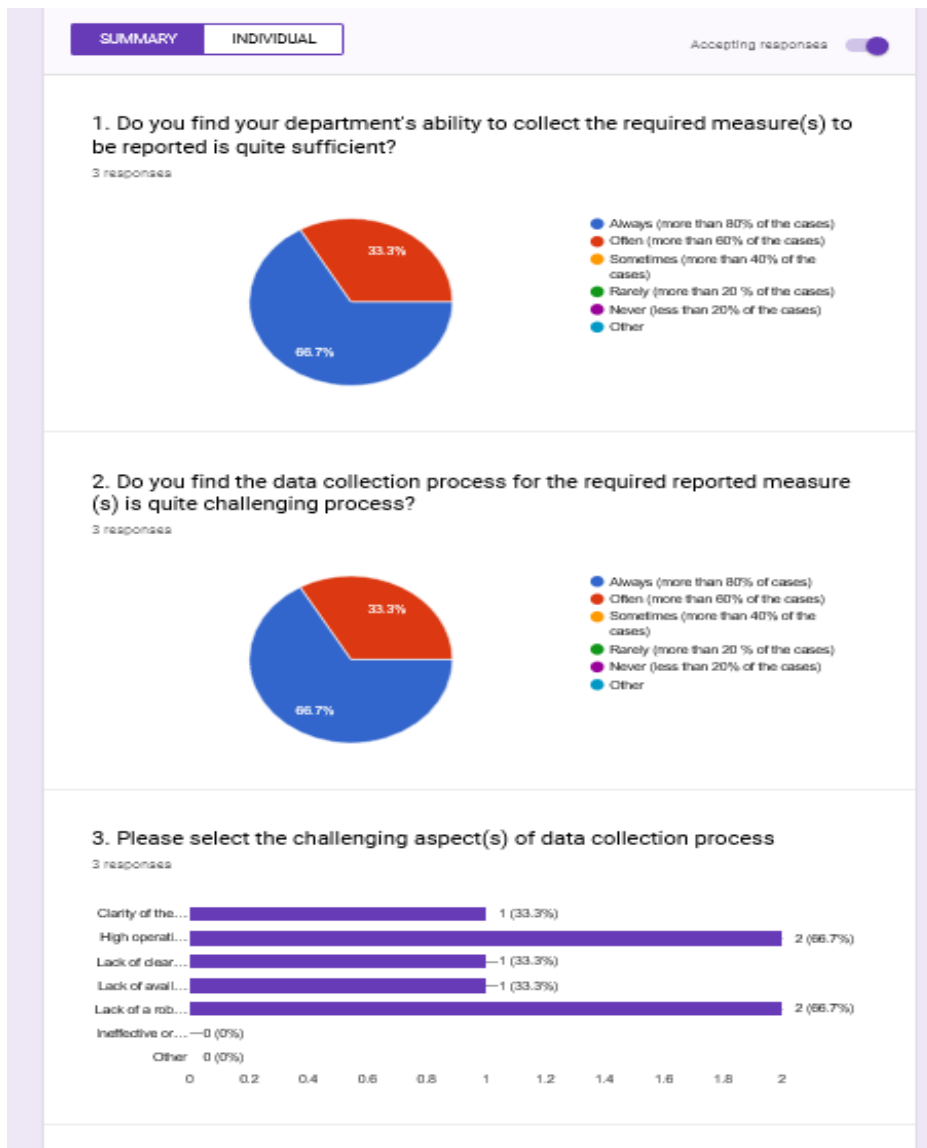


Figure 46 User-friendly summary report for the group responses

Step 4: Request the SWOT analysis report as show in figure 45.

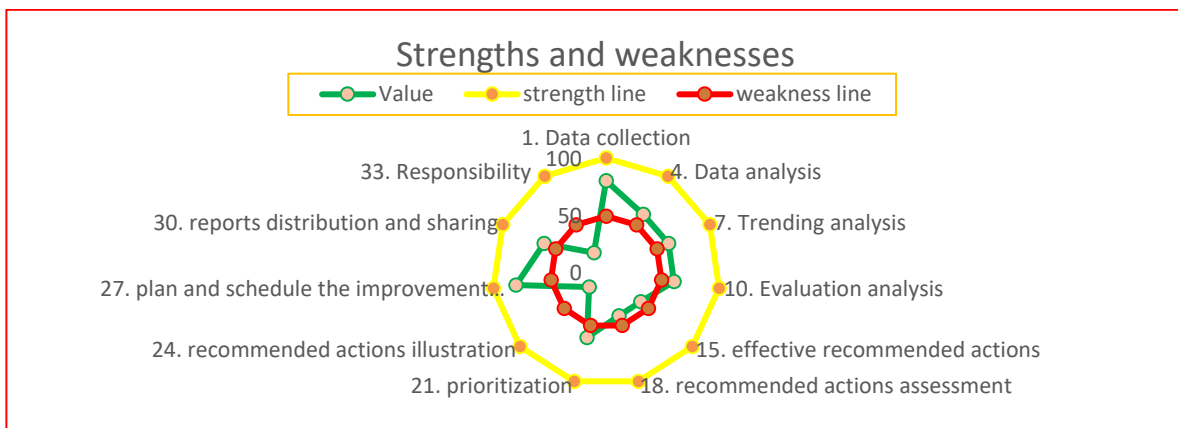


Figure 47 User-friendly report for the internal strengths and weaknesses within the selected functions of maintenance management operations

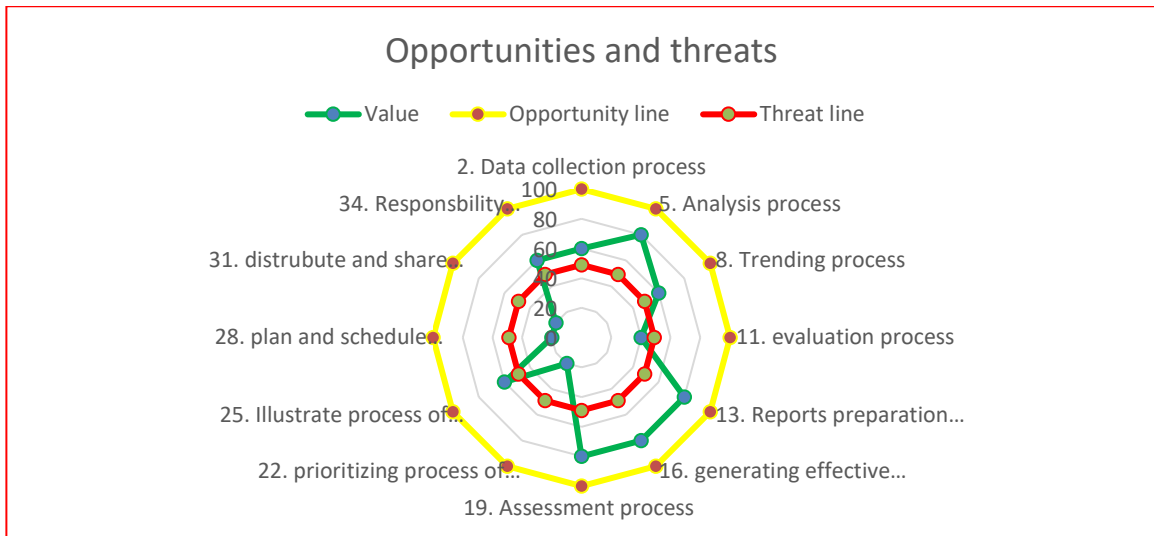


Figure 48 User-friendly report for the external opportunities and challenges within the selected functions of maintenance management operations

## 5. Discussion and Conclusion

The state of the art of the maintenance baseline study is clearly explored within this thesis. The exploration process based on interviews with the professionals in the field of maintenance management indicates, first, that the original version of the self-assessment method is considered as a basement for most of the self-assessment practices within O&G sector. However, it is not used in its original version by the large-scale oil and gas operators have further developed their own customized self-assessment tool with help of modern technology e.g. web-based tools. The second issue, which can be concluded, is that large scale oil and gas operators is mainly interested to update the maintenance management loop, which is within the maintenance baseline study, with modern technology, tools and advanced maintenance techniques. This requirement goes align with the highlighted requirements by Øxnevad & Nielsen (2000), specifically, the need to enhance the maintenance supervision within the maintenance management loop and the need to update the tools, technologies e.g. sensors, big data analytics, advanced maintenance techniques.

However, in order to discuss the explored state of the art with respect to what NPD's wish (1996), as stated by Øxnevad & Nielsen (2000), we might conclude that:

- (1) The Maintenance Baseline Study could clearly contribute to create general improvement of the quality of the operator's system for managing safety-related maintenance. It was clearly observed within this thesis most of the O&G companies has utilized the Maintenance Baseline Study to develop their own maintenance management practices, even more than utilizing it as self-assessment tool
- (2) The Maintenance Baseline Study could provide better predictability for the operators in terms of NPD's expectations and requirements in this area, and even help the companies to explore and predict which advanced technology and techniques shall be allocated in their operations.
- (3) However, the Maintenance Baseline Study is lacking to share the "best practices" and "state of the art" methods and techniques. The lack of literature e.g. academic articles or industrial reports about the use of the maintenance baseline study and their updated versions is quite clear. We could conclude based on the observation within this thesis, that small and medium scale O&G operators have not comprehensively updated the maintenance baseline study as a self-assessment tool in order to share. In the same time, the large-scale O&G operators, which developed their own customized self-assessment tools, had limited sharing practices a gross the sector. Therefore, the feedbacks and shares of the "best practices" and "state of the art" methods and techniques can be considered as very limited at the industry/sector level. Fortunately, the O&M hub is currently playing significant role in providing the secure basement for several scale O&G operators to share and update specially the Maintenance Baseline Study and the general maintenance management frameworks. In fact, this was the reason behind conducting this thesis work at more generic level and rather than conducting a case study at one of the large-scale O&G operators and investigate their customized self-assessment tool. Therefore, the reference of development was the original Maintenance Baseline Study rather than customized self-assessment tool in order to provide

generic model for all companies across the sector, develop, and provide publicly open model for companies that have limited capabilities/resources to develop their own tools.

The industrial needs for updating the self-assessment tool of maintenance management are successfully extracted within this thesis. The first need is to enhance the maintenance supervision within the maintenance management loop by updating its link to the whole asset management loop e.g. PAS 55 standards and life cycle loop e.g. ISO 55001. The second need is to update the internal process of each function within the management loop that presented in Maintenance Baseline Study and to update the tools, technologies e.g. sensors, big data analytics, advanced maintenance techniques (Condition-based maintenance, Predict health monitoring, updated versions of Reliability & Risk centered maintenance, etc.). The third need is to improve the follow-up capabilities of the self-assessment tools in order to be more cost effective to perform the assessment process. However, the thesis work was heavily targeting the last need and therefore more requirements that are detailed were extracted specifically related to this category of the three industrial needs. Thus, it can be concluded based on the requirements analysis that was performed in section 3.2 that user-friendly format and report should be provided, several answering alternatives should be offered, team-sharing and online accessibility should be provided, and most significant the supportive analysis and illustration tool should be integrated into the self-assessment tool. In fact, it can be concluded that the self-assessment style of the Maintenance Baseline Study, in its current form, is time consuming due to the technical issues: large number of questions, their level of clarity, variations in the response styles and lack of analysis that can follow to summaries the results. Moreover, there is a need to enhance the cross-assessment, results sharing and illustration between responsible departments with the same company.

The cost-effective model for self-assessment of maintenance management system based on the extracted needs and potential technologies is sufficiently developed. It is significantly important to highlighted that the developed self-assessment tool was a starting point aiming to mimic the gaps between the original maintenance baseline study, which was developed 20 years ago without clear updates over the time, and the current industrial needs, opportunities and challenges. Therefore, it can be concluded that the generated conceptual solutions for the developed self-assessment tool is satisfactory as they represent the most commonly solutions in the industry, and the extracted industrial needs are representative as they cover wide range of user needs. Moreover, several technical selections related to the development process as using google form, SWOT analysis were justified and can be easily updated or replaced by other solutions as long as the new ones show better performance. Finally, it can be concluded that the implemented validation approach was satisfactory at this stage of development as it could help us to assess how much is the developed model cost effective in a simplified manner.

The developed self-assessment tool based on the maintenance baseline study could show clear enhancement according to the experts' opinions as it requires less time, and it offer a user-friendly visualization of the collected/trended information and their associated results, offer an objective analysis and recommendation action generator. Questions in the maintenance

baseline study should be more clear and easy to understand. The qualitative and quantitative approaches are combined in order to get a more broader and general picture.

For sure, there are needs to:

- (1) Extract more industrial needs by investigating the customized self-assessment tools developed by O&G operators.
- (2) Explore more conceptual solutions that can be proposed and assessed and explore the benefit of “internet of things (IOT)” which might significantly enable the data collection and analysis of the self-assessment process;
- (3) Expand the development to cover the whole maintenance management loop, as the developed model currently covers just three functions within the whole maintenance management loop.
- (4) Validate the developed model in real application and obtain clear figures of the actual benefit of using the developed self-assessment tool.
- (5) Provide a full-automated, flexible to be scaled-up and secure self-assessment tool for company use.

In fact, the direction of large-scale O&G operators in developing their own customized self-assessment tool is in fact validating our reasoning to select the development direction toward enhancing the follow-up capacity via smart tools, instead of updating the management loop and its related tools, technologies e.g. sensors, big data analytics, advanced maintenance techniques. However, the development toward updating the management loop and its related tools, technologies is timely now and recommended. The developed model can be an effective tool to accumulate these proposed updates. This can be a joint project between the O&M hub at CIAM (which have already identified and determined the potential updates) and NPD or other partners to make this intelligent product available for not only the O&G sector. Moreover, conducting purposefully selected case studies is recommended to explore in details the development of the customized self-assessment tools by O&G operators. This might be a great feedback to update the maintenance baseline study and the associated developed model of this thesis. Therefore, in order to have a full validation of the proposed new self-assessment method and see its advantages, it is necessary to launch a pilot project in one of the oil and gas companies where the new self-assessment tool could be implemented in combination with the existing methods that have already been developed earlier by the companies themselves. Companies willing to apply this self-assessment tool will probably have to run it through some customization and adaptation rounds. Such pilot project would be very beneficial for the oil and gas companies, as it would support further development of the self-assessment method to a much higher level.

In summary, those recommended future work might lead us to highly satisfy the NPD’s wish of creating the general improvement of the management quality and excellence of safety-related maintenance operations and gain the benefit of sharing and updating the state of the art and best practice within the O&G sector.

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# Sample - Self-assessment



QUESTIONS

RESPONSES 3

3 responses

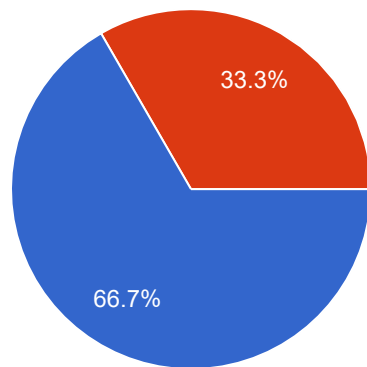


SUMMARY INDIVIDUAL

Accepting responses

1. Do you find your department's ability to collect the required measure (s) to be reported as quite sufficient?

3 responses

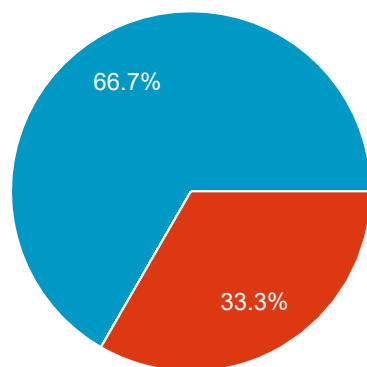


- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20 % of the cases)
- Never (less than 20% of the cases)



2. Do you find the data collection process for the required reported measure(s) is quite challenging process?

3 responses



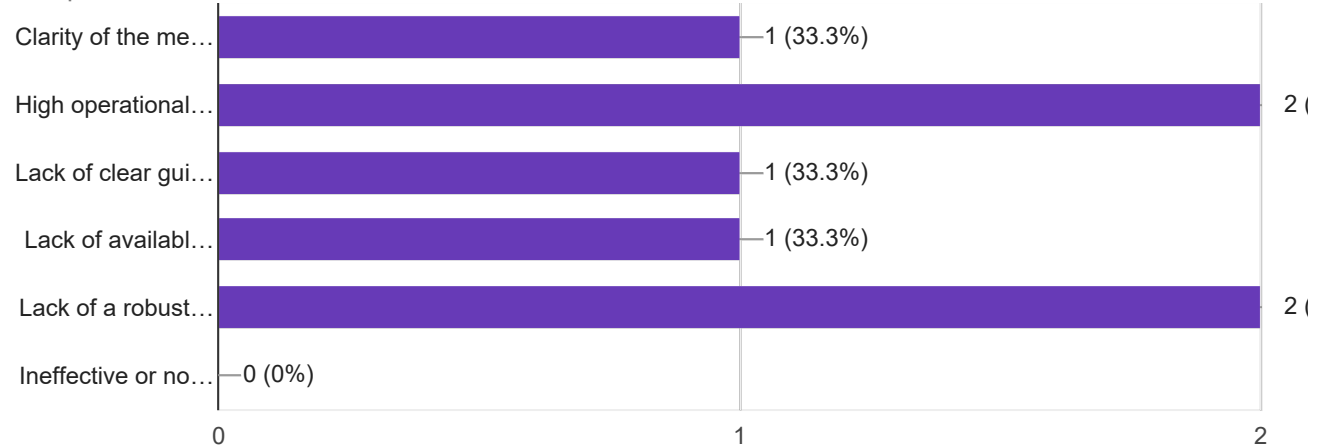
- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20 % of the cases)
- Never (less than 20% of the cases)
- Always (more than 80% of cases)





### 3. Please select the challenging aspect(s) of data collection process

3 responses



### 4. Do the reports provide standard definitions?

0 responses

No responses yet for this question.

### 5. Do the reports provide feedback after job execution?

0 responses

No responses yet for this question.

### 6. Do the reports provide condition reporting for preventive maintenance tasks?

0 responses

No responses yet for this question.

### 7. Do the reports indicate the needs for further analysis for (planning, KPIs, cost, spares, tools etc.)?

0 responses

No responses yet for this question.

### 8. Do the reports provide inputs for design/modifications?

0 responses

No responses yet for this question.

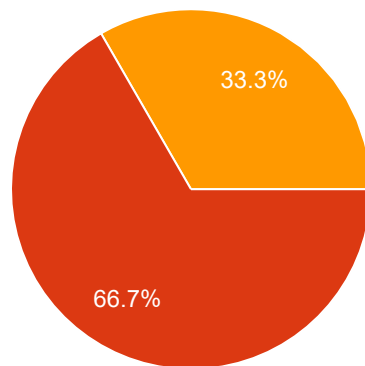
### 9. Do the reports provide feedback into designer/manufacturer/service providers?

0 responses

No responses yet for this question.

### 10. Do you find your department's ability to perform the required analysis on time is quite sufficient?

3 responses

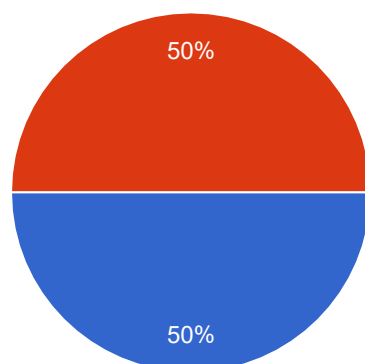


- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)



### 11. Do you find the analysis process for the required reported measure(s) is quite challenging process?

2 responses



- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)



### 12. Please select the challenging aspect(s) of the analysis process

3 responses





13. Do the analysis process provide program review?

0 responses

No responses yet for this question.

14. Do the analysis process provide back tracking - operational support/analysis?

0 responses

No responses yet for this question.

15. Do the analysis process provide design feedback/integrity performance?

0 responses

No responses yet for this question.

16. Do the analysis process provide cost benefit analysis?

0 responses

No responses yet for this question.

17. Do the analysis process provide inputs to new standard?

0 responses

No responses yet for this question.

18. Do you find your department's ability to trend the reported measures over the time is quite sufficient?

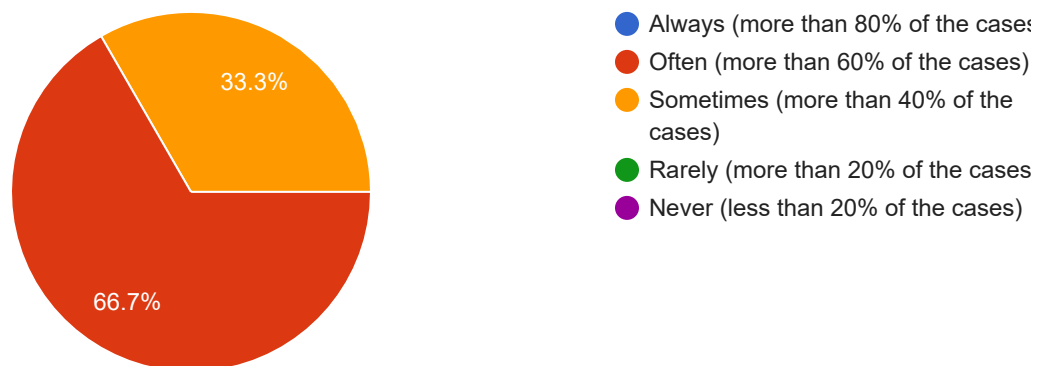
3 responses





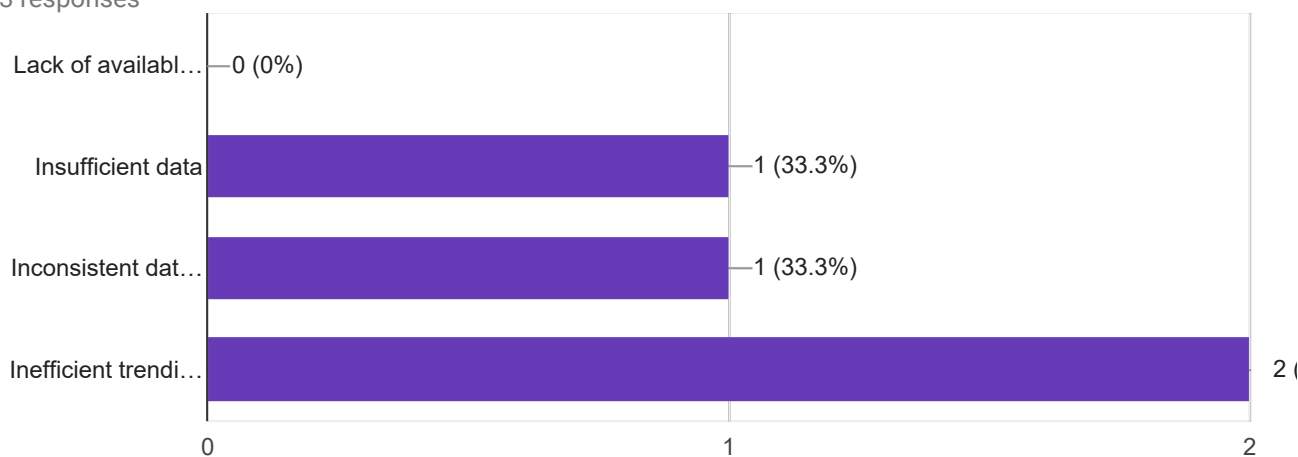
19. Do you find the trending process for the required reported measure(s) is quite challenging process?

3 responses



19. Please select the challenging aspect(s) of the trending process

3 responses



20. Do you find your department's ability to compare between the reported measures at different time intervals is quite sufficient?

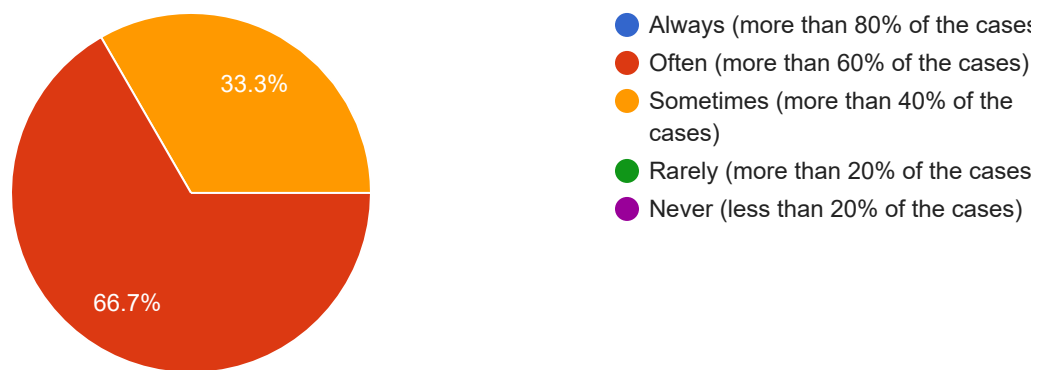
3 responses





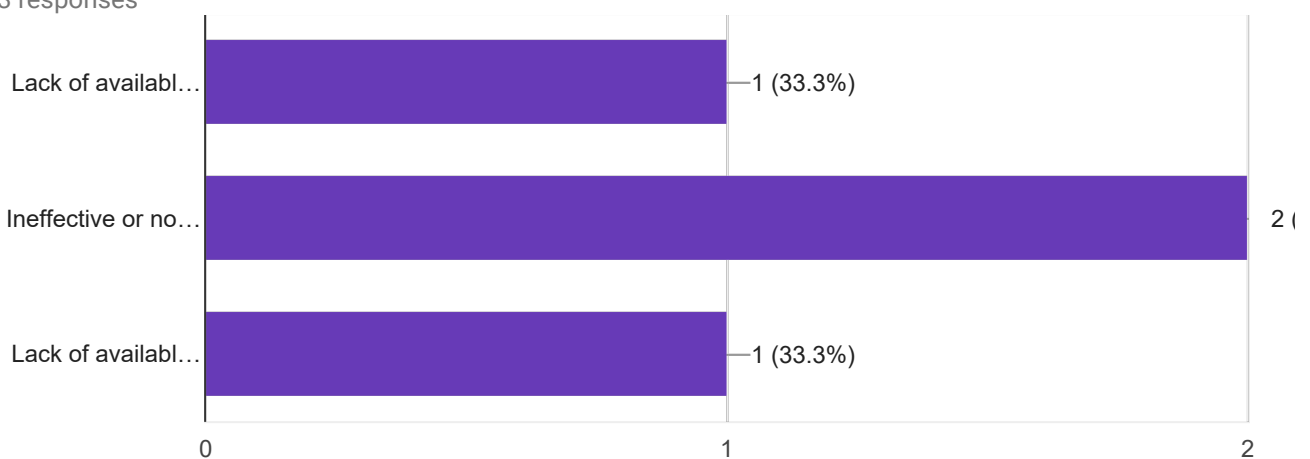
21. Do you find the comparison process for the required reported measure(s) is quite challenging process?

3 responses

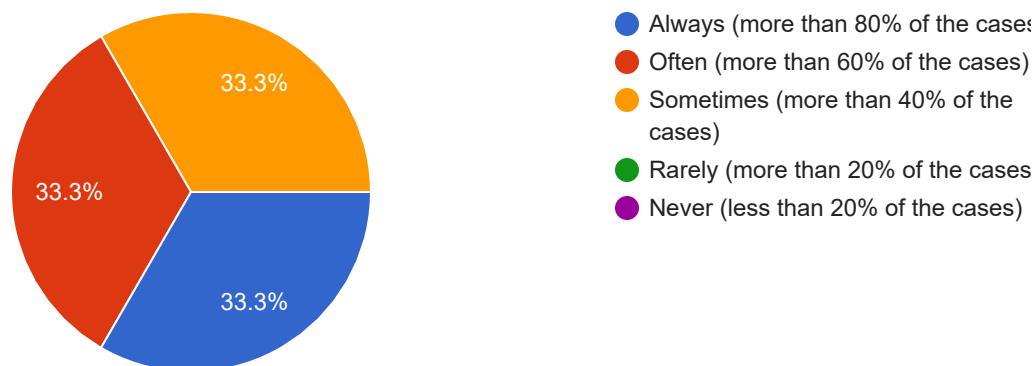


22. Please select the challenging aspect(s) of the comparison process

3 responses

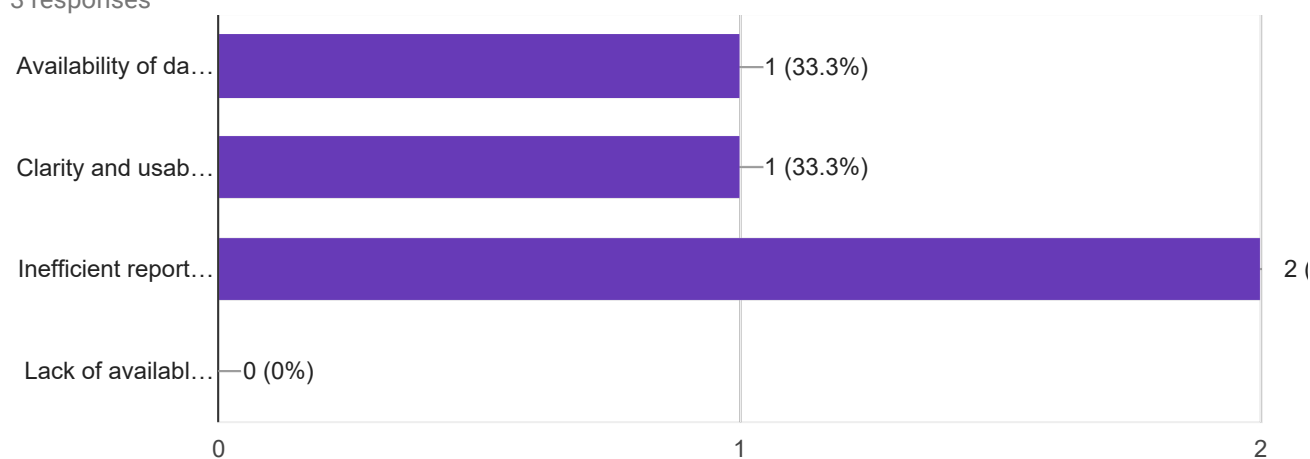


23. Do you find the reports preparation process is quite challenging process?



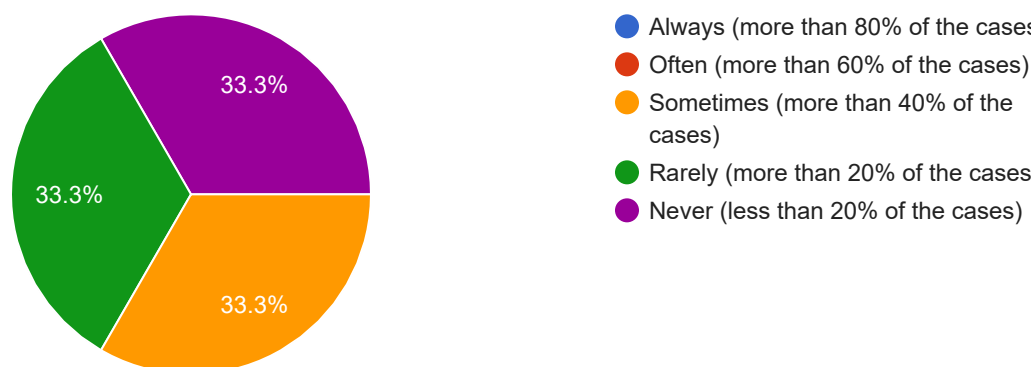
24. Please select the challenging aspect(s) of report preparation process

3 responses



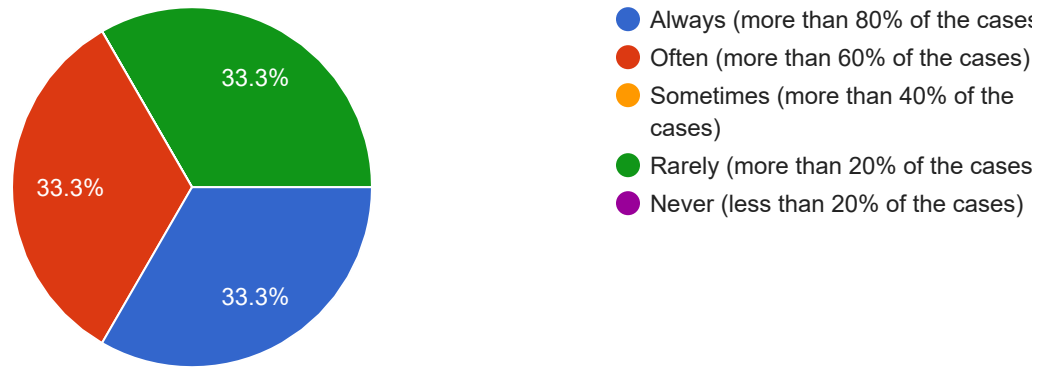
25. Do you find your department's ability to provide effective recommended actions based on the analysed reported measures is quite sufficient?

3 responses



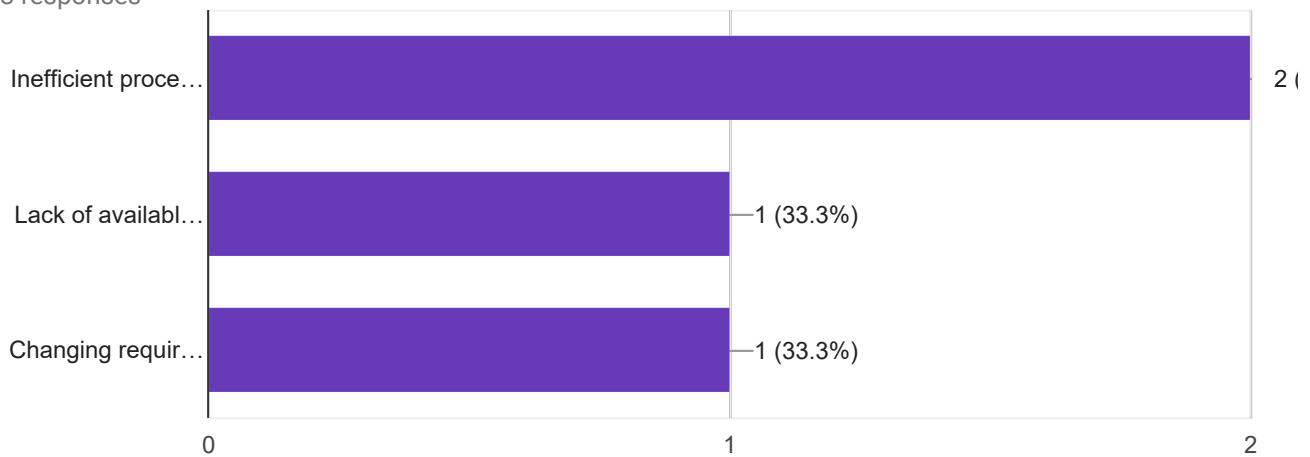
### 26. Do you find the process to generate effective recommended actions is quite challenging process?

3 responses



### 27. Please select the challenging aspect(s) of generating effective recommended action

3 responses



### 28. Do you find your department's ability to assess the recommended actions is quite sufficient?

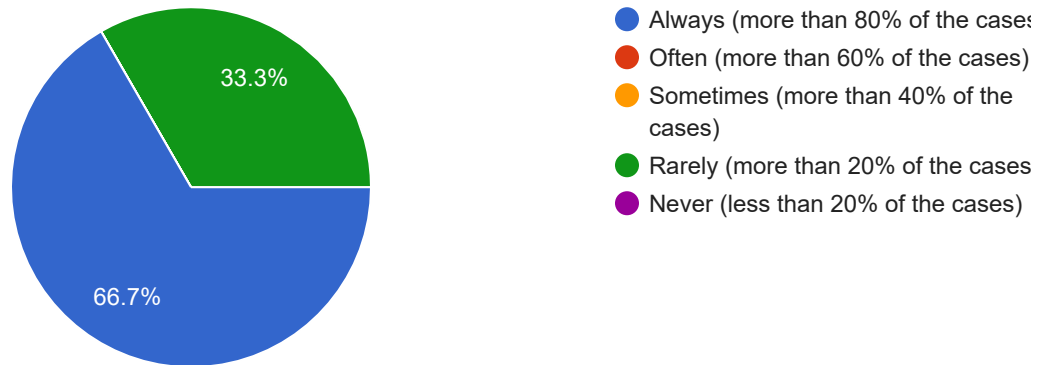
3 responses





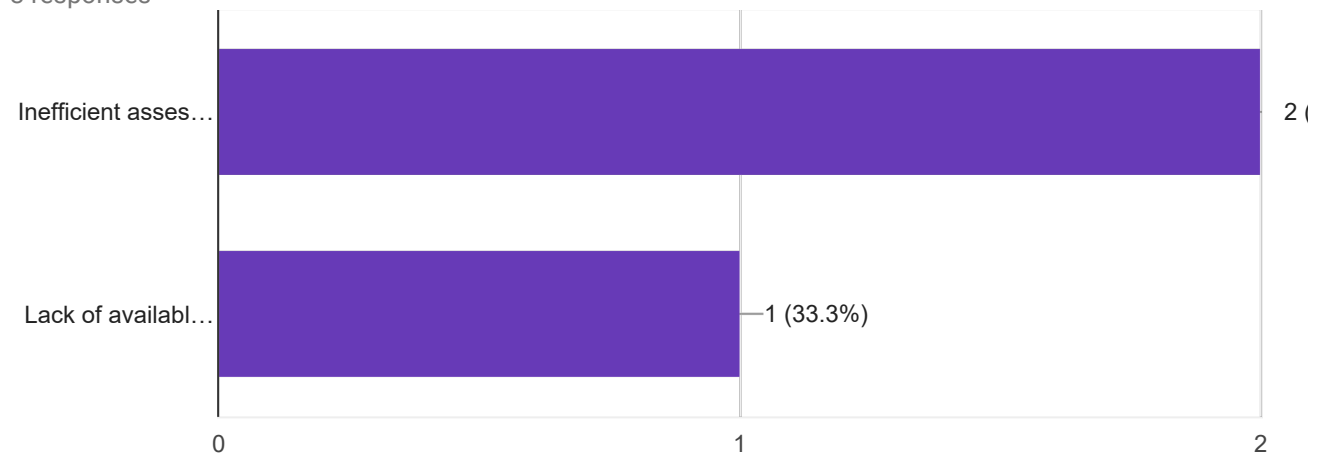
29. Do you find the assessment process of several recommended actions is quite challenging process?

3 responses



30. Please select the challenging aspect(s) of the assessment process of recommended actions

3 responses



31. Do you find your department's ability to define/prioritize the most relevant recommended actions is quite sufficient?

3 responses

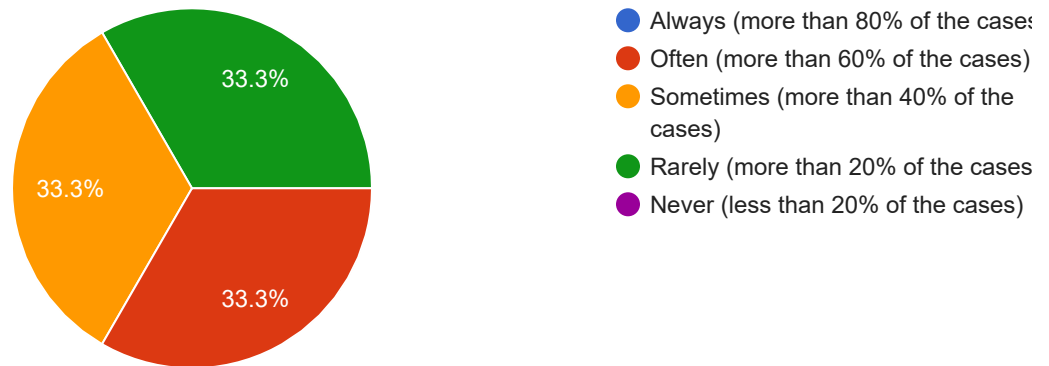






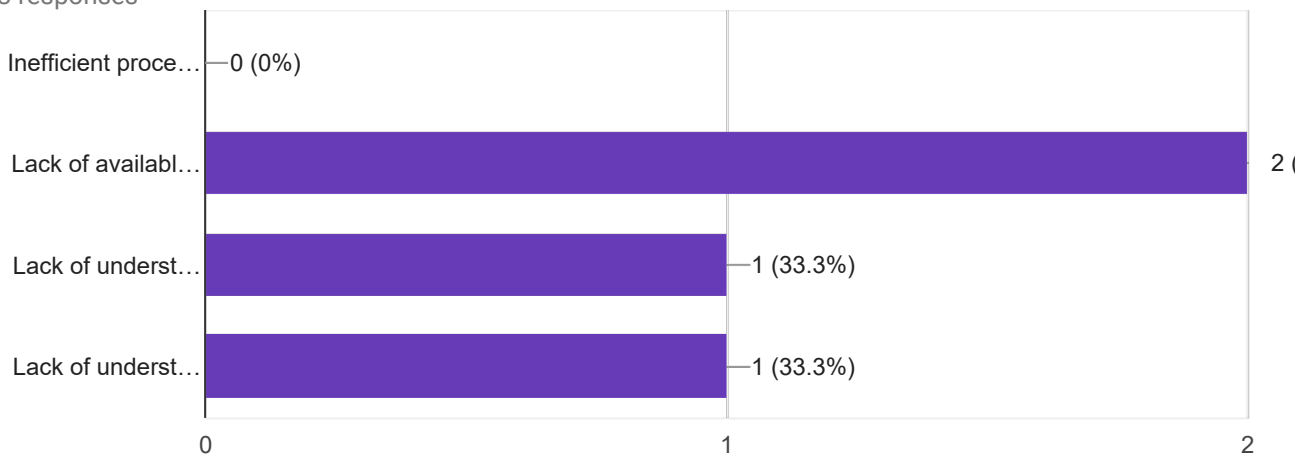
32. Do you find the process to define and prioritize the most relevant recommended actions is quite challenging process?

3 responses



33. Please select the challenging aspect(s) of the process of defining and prioritizing the most relevant recommended actions

3 responses



34. Do you find your department's ability to illustrate the analyses and the recommended actions is quite sufficient?

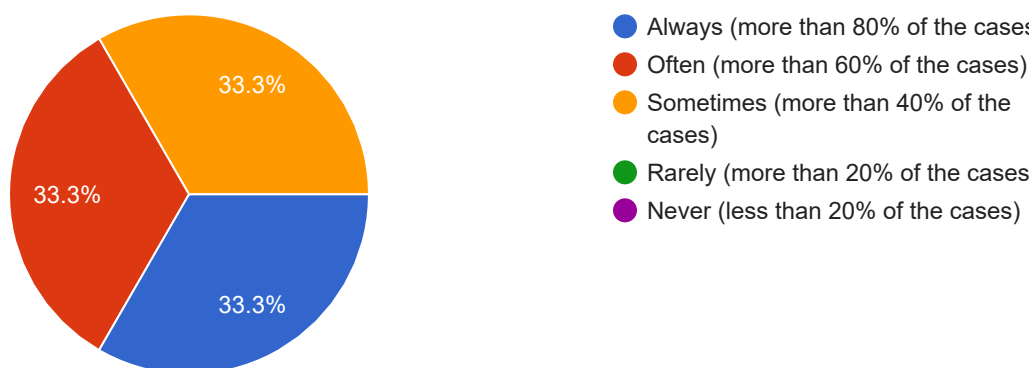
3 responses





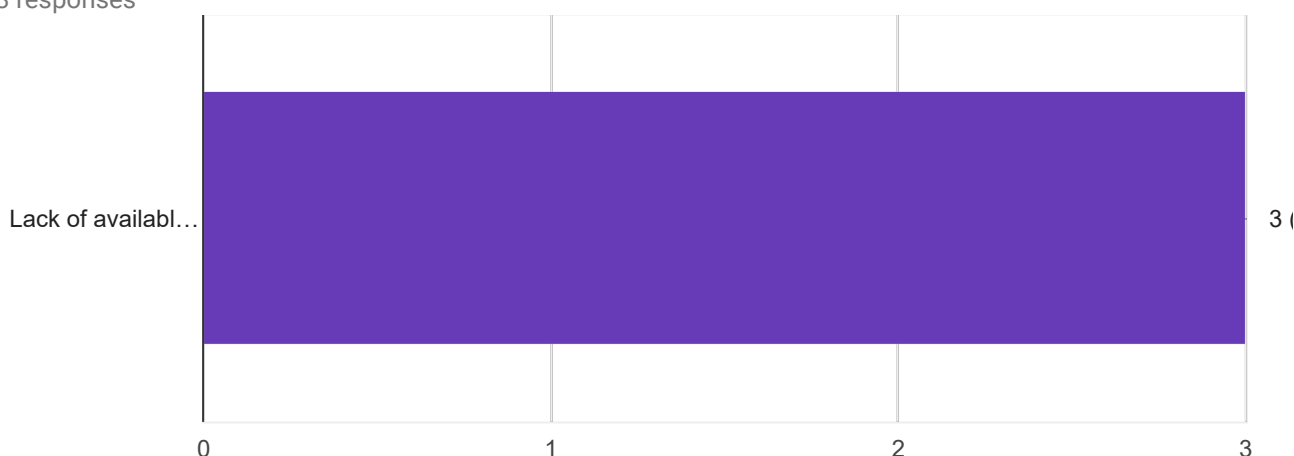
35. Do you find the process to illustrate the analyses and the recommended actions is quite challenging process?

3 responses



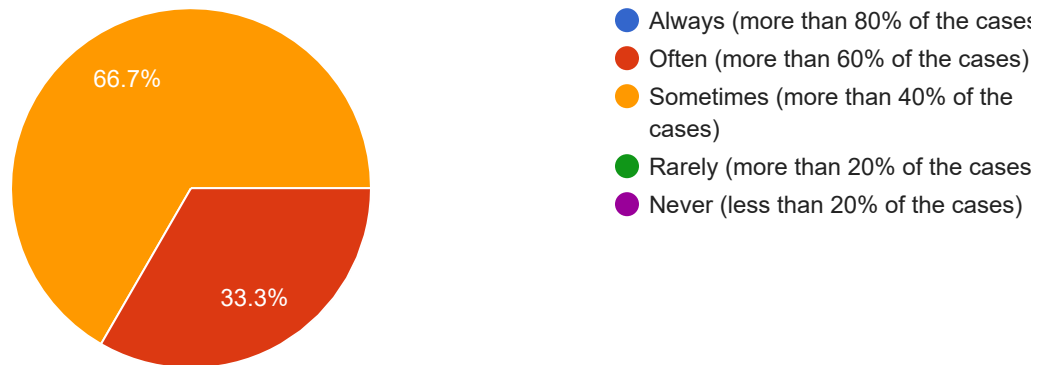
36. Please select the challenging aspect(s) of the process of illustration the analyses and the recommended actions

3 responses



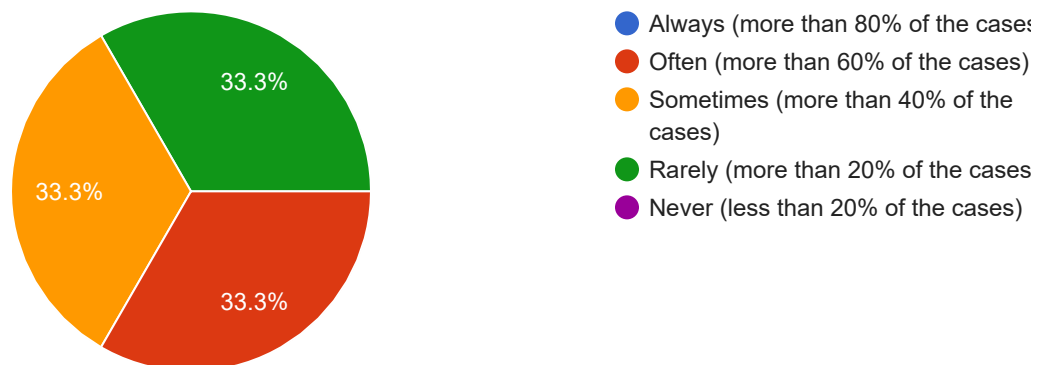
37. Do you find your department's ability to plan and schedule the improvement process related to the most relevant recommended actions is quite sufficient?

3 responses



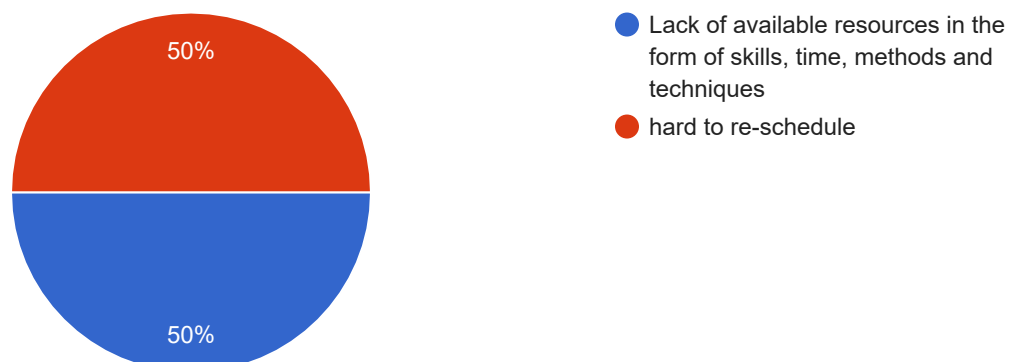
38. Do you find the process to plan and schedule the recommended actions is quite challenging process?

3 responses



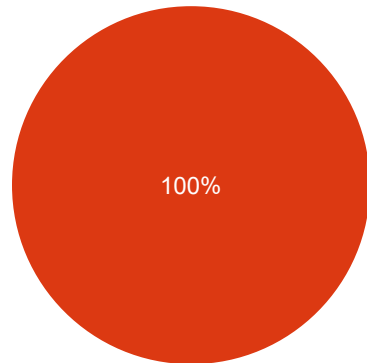
39. Please select the challenging aspect(s) of the process of planning and scheduling the recommended actions

2 responses



40. Do you find your department's ability to distribute the final reports is quite sufficient?

3 responses

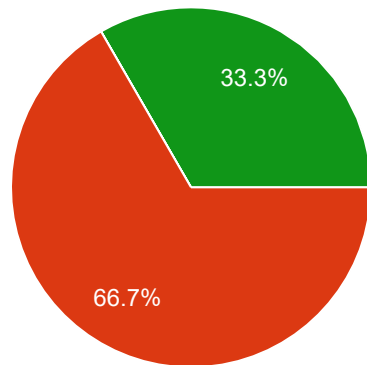


- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)



41. Do you find the process to distribute and share the final reports is quite challenging process?

3 responses



- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)



42. Please select the challenging aspect(s) of the process to distribute and share the final reports

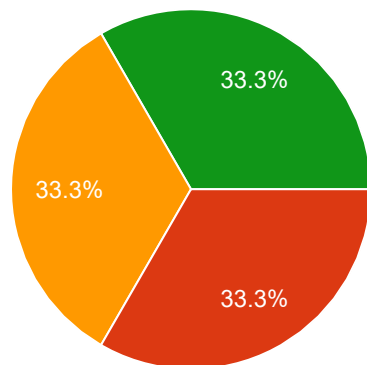
3 responses





43. Do you find your department's responsibility for the whole process (reporting, analysis and improvement management) is quite sufficient?

3 responses

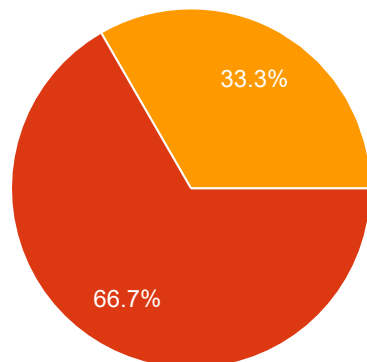


- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)



44. Do you find the responsibility management of such process is quite challenging issue?

3 responses



- Always (more than 80% of the cases)
- Often (more than 60% of the cases)
- Sometimes (more than 40% of the cases)
- Rarely (more than 20% of the cases)
- Never (less than 20% of the cases)



45. Please select the challenging aspect(s) of the responsibility management

3 responses



