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A Study of Maintenance as a Cause to Incidents in the Norwegian Petroleum Industry

Caroline Metcalfe

Proactima, Norway. E-mail: caroline.metcalfe@proactima.com

Willy Røed

Proactima, Norway. E-mail: willy.roed@proactima.com

Eirik Duesten

Proactima, Norway. E-mail: eirik.duesten@proactima.com

May Kristin Bringedal

Proactima, Norway. E-mail: may.bringedal@proactima.com

Rickard Dalman

Proactima, Norway. E-mail: rickard.dalman@proactima.com

Although much attention is given to reveal the causes of hazard and accident situations, the contribution of maintenance specifically is not often investigated or reported. The purpose of this study was to investigate to what extent maintenance is considered to contribute, either directly or indirectly, to hazard and accident situations in the Norwegian petroleum industry. Our goal was not a study as to what extent maintenance contributes to hazard and accident situations, but to better understand how the stakeholders in the Norwegian petroleum industry consider maintenance as a cause to hazard and accident situations. The study is based on a project undertaken for the Norwegian Ocean Industry Authority. The complete report is publicly available in Norwegian. To investigate the above, an assessment of investigated incident reports (including anonymous summaries from such reports) was carried out and information was collected from operators of onshore and fixed offshore facilities in Norway. The information from the operator companies was collected by means of a question set and group discussions with personnel involved in maintenance management, as well as personnel from technical safety and HSE. Based on the study we see there is a potential for better systems and routines to investigate maintenance as a cause of hazard and accident situations. Since there are few systematic processes in the operator companies to investigate maintenance as a cause of hazard and accident situations, it is challenging for the operator companies to take learnings to improve maintenance management to reduce the number and severity of hazard and accident situations in the Norwegian petroleum industry. With a broader view of maintenance and maintenance related activities, more hazard and accident situations were seen to have maintenance related causes.

Keywords: Maintenance, maintenance management, hazard and accident situations, learning & improvement, incident investigation, Norwegian Petroleum Industry, Oil & Gas.

1. Introduction

Several articles and studies have studied the relation between maintenance and accidents/incidents. For example, Okoh and Haugen (2014) found that out of 183 major accidents in the US and Europe, maintenance was linked to 44% of the accidents. These authors also developed classification schemes for causes of maintenance-related major accidents (Okoh and Haugen 2013). Vinnem and Røed (2015) found that almost 60% of the leaks on the Norwegian continental shelf has been associated with manual intervention. This result is in line with results from the annual RNNP risk level project carried out by the Norwegian Ocean Industry Authority, Havtil (former Petroleum Safety Authority).

Although all these efforts and many others have been made, there are limited sources that use

the full breadth of the maintenance concept/definition to evaluate the contribution of maintenance to hazard and accident situations (HAS). The existing literature is also lacking studies into how the operator companies investigate maintenance as a contributing factor for HAS.

This study is based on a project carried out for Havtil to understand the relation between maintenance and HAS within the Norwegian petroleum industry (Proactima 2024). The aim of the project was to explore to what extent maintenance or lack of maintenance is considered to contribute, either directly or indirectly, to HAS in the Norwegian petroleum industry. Using both existing literature and information from operator companies in the Norwegian petroleum industry, the aim was to develop an understanding of how the contribution of maintenance to HAS is evaluated today, and not to quantify the contribution of maintenance to HAS.

Information was collected from most of the operator companies of fixed offshore installations on the Norwegian continental shelf and onshore plants in Norway:

- Aker BP
- ConocoPhillips
- Equinor
- Neptune
- Okea
- Repsol
- Shell (as technical service provider for Gassco)
- Vår Energi

To understand how the operator companies consider the contribution of maintenance related issues to HAS the collected information covered four topics:

(i) How the companies define maintenance and HAS, and use such definitions in practice
(ii) What systems and routines are in place to see the relationship between maintenance and HAS
(iii) What relationships have companies found between maintenance and HAS
(iv) What do the companies do to achieve learning and improvement, given their findings.

For this article, the interest is on the maintenance during the operational phase of the facility. As such, maintenance is defined in line with NORSOK Z-008, ISO 14224 and NS-EN 13306 standards as "the combination of all technical and management actions intended to retain an item in, or restore it to, a state in which it can perform as required" (NORSOK 2017, ISO 2016, CEN 2017). The maintenance management process as presented in NORSOK Z-008 (NORSOK 2017) is shown in Figure 1 and is comprised of three main sections: resources, management of maintenance work processes and results. Please note that we use a "broad" understanding of the maintenance term in this paper, not limited to the maintenance execution activity only, but also including all other maintenance activities mentioned in Figure 1, such as processes and procedures that encompass planning, assessment and improvement of maintenance. NORSOK Z-008 refers to Figure 1 as a management of maintenance work process. This process is sometimes also referred to as a maintenance management loop to emphasize that it is a plan, do, check, act quality improvement loop. For each of the elements of the maintenance management process in Figure 1, the operating companies have work processes to enable sufficient quality.

This study focused not only on incidents, but also near misses and dangerous conditions that can result in incidents. The term hazard and accident situations (HAS) is used hereafter to refer to all conditions where the technical or operational integrity is compromised. This term is in line with the terminology used by Havtil who use the term many times in the regulations but do not explicitly define the term. However, examples are given in the guidance to the management regulation §29 (Havtil 2018) and the use of the term is explained in the Barrier Memorandum published in 2017 (Havtil 2017).

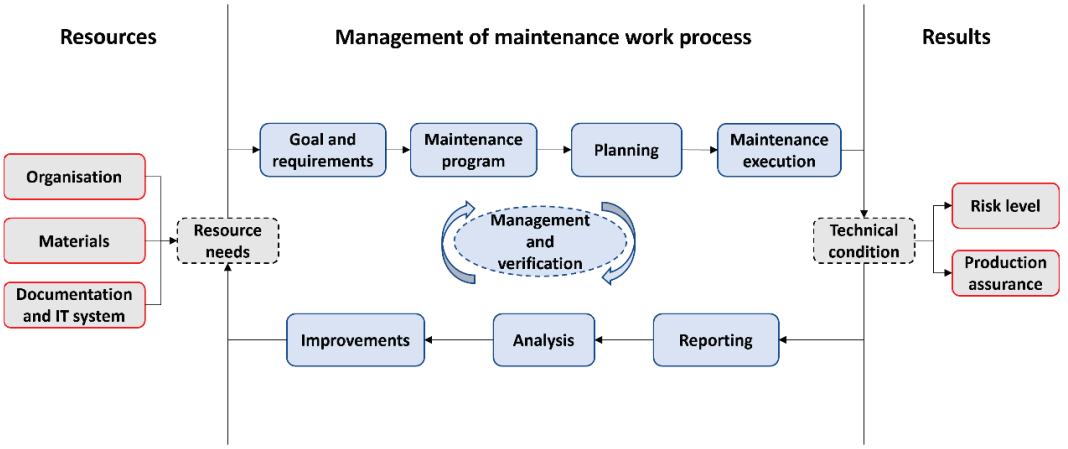

Fig. 1 Management of maintenance process as presented in NORSOK Z-008 (NORSOK 2017)

The next section outlines the methods used to review investigated incident reports and collect information from the operator companies. This is followed by the results of the review and information from the operating companies on the four topics outlined earlier. A discussion of the findings is then presented, followed by the conclusions of the study.

2. Method

Information was gathered in two ways; by reviewing a selection of previously investigated incidents and by gathering information from the operating companies in the form of a question set and follow-up group discussions. These aspects are described in Section 2.1 and 2.2.

2.1. Review of investigated incidents

The reports of investigated incidents reviewed as part of the study were from two different sources. The first source is a subsection of publicly available investigation reports. The investigation reports reviewed were the same selection as used during an earlier Havtil report titled "Læring etter hendelser" (Learning from incidents) (Proactima 2022). One of the investigation reports covered an incident which occurred during the construction phase and thus was deemed not relevant for this study and was excluded from the further analysis. The 17 reports within this subset give an overview of serious incidents in Norwegian petroleum operations between 2007 and 2021, as well as two older serious incidents (1977 and 1997). Most of the incidents were investigated by Havtil, but there are also some incidents investigated by other stakeholders such as other regulators and operator companies. For the remaining parts of the paper, we refer to these investigations as the public investigations.

The second source of investigated incidents is Offshore Norge's database of hydrocarbon leaks on the NCS (Offshore Norge n.d.). This source provided a coherent source of hydrocarbon leaks with an initial leakage rate of >0.1 kg/s from the process area of offshore production facilities since 2013. Since maintenance practice and follow-up may have changed over time, we chose to focus on the most recent leaks in the period 2018-2021. For these leaks, additional information was available in terms of a cause analysis available on Offshore Norge's webpage. This dataset consists of 23 incidents. As the incidents in the Offshore Norge database are anonymous it is possible that an incident can be present in both data sources.

For the incidents in both data sources, it was evaluated if maintenance was a contributing factor based on the information available and which elements in the maintenance management process (Figure 1) can be identified as contributing factors. It should be noted that for each incident, all

elements in Figure 1 that were identified to be a contributing factor are included in the results. Therefore, each incident can have more than one element of the maintenance management process identified as a contributing factor. This evaluation was a qualitative evaluation based on our experience and interpretation of the information contained in the public investigation and the anonymous information in the Offshore Norge database.

2.2. Information from operator companies

Information was collected from operator companies in the form of a question set and a follow-up group discussion on Teams with those who were involved in responding to the question set. Both the question set and the group discussion covered the four topics presented in the introduction to the paper.

Each operating company decided which personnel contributed to responding to the question set and attending the group discussion. Our recommendation was that personnel from maintenance management, HSE and technical safety should be involved.

The question set consisted of 59 questions to enable a good foundational understanding of the processes and procedures the companies have for assessment of maintenance and HAS, both separately and in relation to each other. It was requested that personnel who were actively involved in responding to the question set also participated in the group discussion. Each group discussion was scheduled for 3 hours, with some using the full time and others finishing beforehand.

3. Results

3.1. Review of investigated incidents

Of the 17 public investigation reports reviewed, 10 (59%) concluded that maintenance was a contributing factor to the incident. Our evaluation is that maintenance was a contributing factor in all the 17 incidents. Table 1 shows the number of times each element of the maintenance management process was identified as a contributing factor for the reviewed incidents. Based on our evaluation of the investigation reports, and with reference to Figure 1, deviations related to "goals and requirements" was identified as a contributing factor in 16 of the 17 incidents and deviations related to "maintenance execution" was identified as a contributing factor in 2 of the 17 incidents.

Of the 23 anonymous incidents reviewed from the Offshore Norge database, our evaluation is that maintenance, in the broad understanding of the term as explained in the introduction to the paper, was a contributing factor in 18 incidents. Table 1 shows which elements of the maintenance management process that were identified as a contributing factor for these 18 incidents. Maintenance execution was identified as a contributing factor in 13 of the 18 incidents, whereas goals and requirements were only identified in 1 of the 18 incidents.

Table 1. Summary of which elements in the maintenance process contributed to the reviewed investigated incidents

Elements in maintenance management loop	Havtil investigation reports (17 total)	Offshore Norge's hydrocarbon leak database (18 total)
Goals and requirements	16	1
Maintenance programme	8	2
Planning	6	6
Maintenance execution	2	13
Reporting	7	2
Analysis	9	1
Improvements	6	-
Resource needs	-	2

3.2. Review of information from operator companies' representatives

3.2.1. *Definition of maintenance and HAS*

All operator companies defined maintenance in line with the definition presented in the introduction. When replying to the question set, all operator companies defined HAS in line with Havtil's use of the term. However, in the group discussion it became apparent that most

companies only register incidents or near misses in the incident database system. There was also some misalignment between some of the participants in the understanding of maintenance, where some participants had a narrower understanding of what is "maintenance related" than the "broad" interpretation of maintenance provided in the referenced standards and in Figure 1.

3.2.2. *Systems and routines to see the relationship between maintenance and HAS*

All companies had separate software for maintenance management and HAS management. All companies used a CMMS (Computerised Maintenance Management System) for registration and handling of equipment defects, failures and dangerous conditions. There was high awareness of defects, failures and dangerous conditions for equipment defined as barrier elements, with less awareness for equipment not associated with barrier functions.

All companies had an incident database system for registering and following up HAS, with a greater focus on incidents and near misses and less or no focus on registration and follow up of dangerous conditions that might result in an incident. Dangerous failures or conditions of barrier elements are usually registered in the incident database system. The registration and following up of dangerous conditions not related to barrier functions was done to a lesser extent or not at all.

No companies had cause categories or contributing factor categorisation related to the entire breadth of the maintenance concept neither in the CMMS nor the incident database system. One company had one general category for maintenance in the incident database system. Another company categorised the entry based on organisation. A third company had a wider range of categories related to maintenance, but did not include all elements in the maintenance management process, ref. Figure 1.

After receiving the question set, one company performed an updated data analysis and presentation of the information in the incident database to answer some of the questions asked. However, this had not been implemented before being prompted by the question set and thus the updated presentation was not used actively in the company to assess cases to incidents related to maintenance, at least not before the study.

All companies performed reviews of equipment defects, failures and dangerous conditions recorded in the CMMS. However, it varied between the companies as to how the registrations were used to analyse in the purpose of improving the processes within maintenance management process.

Based on the answers to the question set and the group discussions, it was our impression that all companies have few established routines and systems to assess the relationship between maintenance and HAS. The companies had, in general, more focus on identifying the causes of single HAS and less focus on performing thematic assessments across multiple HAS with the purpose of identifying common causes. All the companies described challenges in identifying and registering relevant data, as well as utilizing existing information to analyse the correlation between maintenance and HAS.

3.2.3. Understanding of the relationship between maintenance and HAS

Within the question set, the operator companies were asked "To what extent does inadequate, deficient and incorrect execution of maintenance contribute to dangerous situations and incidents?". Table 2 shows the responses. Most of the operator companies answered that inadequate, deficient and incorrect execution of maintenance contributes to a small extent to dangerous situations and incidents.

The operator companies were also asked as part of the question set:

- Which element(s) contributes to the greatest extent to undesirable conditions that can lead to dangerous situations and further to incidents?
- Which element(s) would you prioritize to improve/strengthen to prevent dangerous situations and incidents?

The responses from the 8 operator companies on these two questions are shown in Table 3. There is a difference between which elements the operator companies indicated as contributing to dangerous situations and incidents and which elements the operator companies would prioritise to improve to prevent dangerous situations and incidents.

Table 2. Operator companies' response to the question "To what extent does inadequate, deficient and incorrect execution of maintenance contribute to dangerous situations?"

	Inadequate maintenance	Deficient maintenance	Incorrect execution of maintenance
Not specified	1	1	1
Very small extent	1	1	1
small extent	5	5	4
Not sure	0	0	0
Some extent	0	0	1
Large extent	1	1	1

Maintenance execution, followed by maintenance programme and planning are the elements that the operator companies indicated contribute the most to undesirable conditions. However, analysis, followed by improvement and maintenance execution were the elements most chosen to prioritise strengthening to prevent dangerous situations and incidents.

Each operator company was able to choose the number of elements selected for each question. Although each question had 17 responses not all operator companies gave the same number of responses to each question; for example, one company only selected on element which to the greatest extent contributes to undesirable conditions but selected 3 elements that they would prioritise to improve/strengthen. There were only 4 instances in which an operator company selected the same element which to the greatest extent contributes to undesirable conditions and that would be prioritised to improve/strengthen.

Table 3. Operator companies' responses to which elements contribute to undesirable conditions and which to prioritize to improve/strengthen

Elements in maintenance management process	Contribute to undesirable conditions that can lead to dangerous situations and further to incidents?	Prioritise to improve/ strengthen to prevent dangerous situations and incidents?
Goals and requirements	1	1
Maintenance programme	3	0
Planning	3	2
Maintenance execution	4	3
Reporting	1	2
Analysis	2	4
Improvements	0	3
All elements	1	0
Not specified	2	2
Total	17	17

3.2.4. Achieve learning and improvement given findings

All operator companies, in general, had a system to ensure learning from incident and near-miss reporting. All companies used the information recorded in the incident database system as the basis for such learning. Some companies also stated that they use the information recorded in their CMMS for the same purpose. Companies that also operate internationally expressed that they take learnings from across the entire company.

Some companies also had systems or routines in place to learn from incidents in other companies within the industry. None of the companies had systems and routines to learn from relevant incidents in other industries.

All the operator companies expressed that it is challenging to use existing information regarding the relationship between maintenance and HAS for learning and improvement.

4. Discussion

The review of investigated incidents shows that maintenance is a contributing factor in a significant number of these incidents when a broad understanding of the term maintenance is used. Through the review of the investigated incidents , it can be seen that maintenance is a prominent underlying cause when a broad definition of maintenance is used.

There is a difference between the public investigations and the Offshore Norge data sources in which elements in the maintenance management process contribute to HAS. The public investigations indicate that maintenance execution does not have a prominent contribution to HAS, as it was identified as a contributing factor in only 1 of the 17 reports. However, for the anonymous incidents in Offshore Norge's database, maintenance execution was identified as a contributing factor in 15 of the 18 maintenance related incidents. However, it is worth noting that incorrect execution can be due to errors made in the planning phase, but the mistake materializes in the execution phase.

A plausible explanation for the difference in which elements of the maintenance management process contribute to HAS is that hydrocarbon leaks, which are reported in the Offshore Norge database, are primarily related to maintenance activities, for example pigging, use of temporary hoses and intervention of valves whereas the public investigated incident reports reviewed are to a lesser extent related to execution of maintenance activities.

The operator companies have few systematic procedures and processes in place to analyse the relationship between maintenance and HAS. There is little flow of information between the CMMS and incident database system and little to no analysis done to see how the information in the CMMS influences HAS reported in the incident database system.

Without procedures and processes to register and analyse the appropriate data, the relationship between maintenance and HAS, it is difficult to take learnings and improvements of maintenance management that reduce the number and severity of HAS. Also, there is variation between the different operators in learnings taken from other companies both within the industry and from other industries that use similar equipment.

There is difference between our review of investigated incident reports , that maintenance contributes to a significant number of HAS, and that most of the operator companies answering that inadequate, deficient and incorrect maintenance to a small extent contributes to HAS. This could be due to the extent that the operator companies use the breadth of the maintenance management concept: While we have used the broad definition of maintenance as explained in the introduction to the paper, it is our impression that operating companies only consider the contribution of maintenance to HAS when an error was made during the execution of the maintenance activity. Another possible explanation is that without systematic procedures and processes for registration and analysis, it is difficult to understand to the full extent the relationship between maintenance and HAS.

5. Conclusion

The review of investigated incident reports shows that there is an improvement potential regarding how the relation between maintenance and HAS is considered. By including the broad definition of maintenance, the relationship between maintenance and HAS can potentially become more visible.

Within the operator companies there is a potential to improve systems and routines to investigate, register and analyse the contribution of maintenance to HAS. With few systematic processes to investigate the relation between maintenance and HAS, it can be difficult for the operator companies to achieve a good understanding of how maintenance contributes to HAS. This in turn makes it challenging for them to take learnings to improve maintenance management with a goal to reduce the number and severity of HAS in the Norwegian petroleum industry.

There is a huge amount of maintenance related information available in the operating companies that could be better used to improve safety in the Norwegian petroleum industry if the data is given the deserved attention.

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