Safety Science 79 (2015) 206–212

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Improving the risk assessments of critical operations to better reflect uncertainties and the unforeseen

Henning Veland, Terje Aven *

University of Stavanger, 4036 Stavanger, Norway

ARTICLE INFO

Article history:
Received 2 January 2015
Received in revised form 20 May 2015
Accepted 17 June 2015
Available online 30 June 2015

Keywords:
Risk
Uncertainties
Surprises
Risk assessment
Safe job analysis
Critical operations

ABSTRACT

In this paper we address risk assessments of critical operations and in particular the safe job analysis, the main aim being to improve these risk assessments by better reflecting uncertainties and the unforeseen. The work is based on the conviction that current practice does not adequately deal with potential surprises and the knowledge dimension of risk. An adjusted risk assessment approach is presented and illustrated using an example from the oil and gas industry. Several incidents in the oil and gas industry in recent years have shown a lack of proper understanding of risk, and the present paper is to be seen as a contribution to the work of improving the understanding of risk on the part of the personnel involved in critical operations.

1. Introduction

Several operations are carried out every day on offshore oil and gas installations (e.g. production platforms) with various levels of criticality with respect to safety. Some examples are maintenance work on equipment or pipes containing hydrocarbons, lifting of heavy equipment, and production and exploration drilling. Such operations often have the potential for severe consequences if a barrier (operational, technical or human) should fail. To deal with risk related to such operations, the industry has developed and applies several standardised operational risk assessments, including a system for work permits and Safe Job Analysis (SJA). The aim of these risk assessments is to ensure that the risk is adequately handled and is at a sufficiently low level when carrying out the operations. For some works presenting and discussing such operational assessments, see for example Vinnem (2014), Meyer and Reniers (2013) and Leistad and Bradley (2009).

The Petroleum Safety Authority Norway (PSA-N) conducts independent investigations following accidents and incidents in the oil and gas industry on the Norwegian continental shelf. According to the PSA-N, a common indirect cause of these unwanted events is related to a poor understanding of risk on the part of the personnel involved, at both the sharp end (operators) and/or the blunt end (planners/managers). This observation has recently been referred to in a publication from PSA-N, in which the status and signals of safety in the Norwegian oil and gas industry have been summarised (PSA-N, 2012):

> *"A number of technical, operational and organisational factors can individually or collectively cause an accident and influence its development. But the question is how the industry and the authorities work to prevent major mishaps and monitor risk in the Norwegian petroleum industry. This is first and foremost a matter of risk understanding and management in the companies, work to reduce uncertainty, and ensuring good emergency preparedness."*

Many of the investigations have uncovered that there are huge differences in the understanding of risk between the workers. Some may have the necessary insights, while others may have severe knowledge holes. The reason for this lack of knowledge is often poor communication. In other cases all the personnel involved have a poor understanding of risk, for example as a result of lack of information. A risk assessment constitutes an important tool for ensuring a proper understanding of risk. However, a risk assessment does not provide a guarantee that the relevant personnel have obtained a good understanding of risk. There may be several obstacles, including:

(1) The risk assessment itself may be poor, in the sense that it does not capture important risk issues.
(2) The follow-up of the insights uncovered during the risk assessment may be poor. Hazardous conditions may have

* Corresponding author. Tel.: +47 5183 2267; fax: +47 5183 1730.
E-mail address: terje.aven@uis.no (T. Aven).

http://dx.doi.org/10.1016/j.ssci.2015.06.012
0925-7535/

been identified in the risk assessment, but the safety culture or underlying matters or agendas may lead the personnel to not handle risk in an appropriate manner.

The latter item is as important as the former, but the present paper restricts attention to item 1. We will argue that there is a potential for considerable improvements to current risk assessment practice in the industry. The prevailing thinking pays too little attention to the knowledge dimension of risk and the potential for surprises. This issue has been thoroughly discussed in recent papers (e.g. Aven, 2013; Aven and Krohn, 2014). The main arguments can be summarised as follows:

(a) Common ways of summarising risk are based on assigned probabilities, for example by using risk matrices. This approach does usually not reflect the strength of knowledge that supports the assessment, and the produced probability-based risk description can seriously mislead decision makers. We may have two situations with identical assigned probabilities, but in one case the strength of knowledge is strong, and in the other it is weak. The assigned probability itself does not bring forward this aspect of risk. A risk event that is judged to be acceptable based on a probability assessment associated with a weak strength of knowledge should be given less weight when making a decision compared to a situation where the same assessment is associated with a strong strength of knowledge.
(b) Common risk assessment approaches do not pay sufficient attention to the fact that assumptions and prevailing explanations and beliefs may conceal important aspects of uncertainties and risk.

In this paper we present and discuss an adjusted risk assessment method that meets these challenges (a) and (b), using the Safe Job Analysis (SJA) as an example. The main aim of the paper is to improve the current risk analyses of critical operations by better reflecting uncertainties and the unforeseen. To illustrate the analysis we will consider an application from the oil and gas industry. The general method is presented in Section 2, whereas Section 3 introduces a case study that will be used to demonstrate the key features of the adjusted risk assessment and practical implications for decision-making (Section 4). The final Section 5 provides a summary and conclusion. The case study and the generic SJA methodology is from the Norwegian oil and gas industry, but the method presented and the following discussion are also relevant for other areas of application.

2. An adjusted safe job analysis

The main objective of the adjusted SJA is to improve the risk understanding of personnel involved in the critical operation by:

- Highlighting the strength of knowledge supporting the assigned probability judgements.
- Providing new insights on the risk events assessed to have high consequences and low probabilities.
- Identifying and assessing any potential surprises.

The adjusted risk assessment process involves two analyst teams, referred to as teams I and II, see Fig. 1. Team II should have an unbiased focus in the sense that members of team II should not have been participating in any previous planning of the operation. The idea is that the second analysis team should see the critical operation with new eyes, thus better enabling them to identify any aspects of risk that team I did not identify.

The adjusted risk assessment process has four main stages. In **Stage 1**, analyst team I performs a standard risk assessment, analyses risk and describes risk according to (A_1', C_1', Q_1, K_1) (Aven, 2013). Here A_1' and C_1' are the specific events and consequences identified in the analysis, Q_1 a description/measurement of uncertainty (typically using probability) of A_1' and C_1', and K_1 is the background knowledge on which A_1', C_1' and Q_1 are based: data, information, justified beliefs (models, probability models, expert judgements, assumptions).

In **Stage 2**, analyst team I performs a self-evaluation of (A_1', C_1', Q_1, K_1), having a focus on the rationale for (A_1', C_1', Q_1, K_1) and highlighting the strength of knowledge of K_1. The updated risk description is denoted (A_2', C_2', Q_2, K_2). In many cases there would be no difference in A, C and Q, but the background knowledge K always changes after this review has been performed, adding a quality control of the various elements of the analysis process and a special judgement of the strength of knowledge of K_1.

In **Stage 3**, analyst team II challenges team I and their mental models (assumptions etc.), acting as a red team (the devil's advocate) and for example:

- Argues for the occurrence of events with assigned negligible probabilities,
- Searches for unknown knowns (events that are known by others but not team I),
- Checks how signals and warnings have been reflected.

A main purpose of the stage is to identify and assess potential surprises.

In the final **Stage 4**, the two analyst teams are to provide a joint risk description (A_3', C_3', Q_3, K_3), reflecting the input from both teams. The risk description provides a basis for understanding risk and supporting the decision-making.

SJA is a well established risk assessment method. The adjusted approach builds on the traditional one but adds some stages as described above. The methodology is framed in a general risk description, and expresses risk, using the generic risk set up of (A′, C′, Q, K). Expert elicitation knowledge may provide input to the uncertainty judgments Q and may form important aspects of the background knowledge K. The methodology specifically addresses the issue of surprises relative to current knowledge and beliefs, which is not commonly captured by existing approaches (such as standard SJA).

The analysis process could be rather resource demanding, but the full process should only be used in selected situations when the criticalities are considered high. In practice simplified schemes could be developed to make the process feasible.

3. Case study: offshore installation

In this section we will discuss how the adjusted risk assessment can be used for conducting an SJA on an offshore platform.

3.1. Background

In 2008 a serious oil leak incident occurred on a Norwegian offshore oil and gas installation (StatoilHydro, 2008). The oil leaked out inside a vertical passageway shaft located within one of the three 175-m tall concrete legs of the installation. See Fig. 2 for a similar neighbouring installation that has an additional fourth concrete leg.

The incident occurred during modification work inside the passageway shaft at 61 m above sea level. A special tool called a hot tap machine was used to contain the flow of hydrocarbon fluids while performing work on a pipe bend section that contained oil

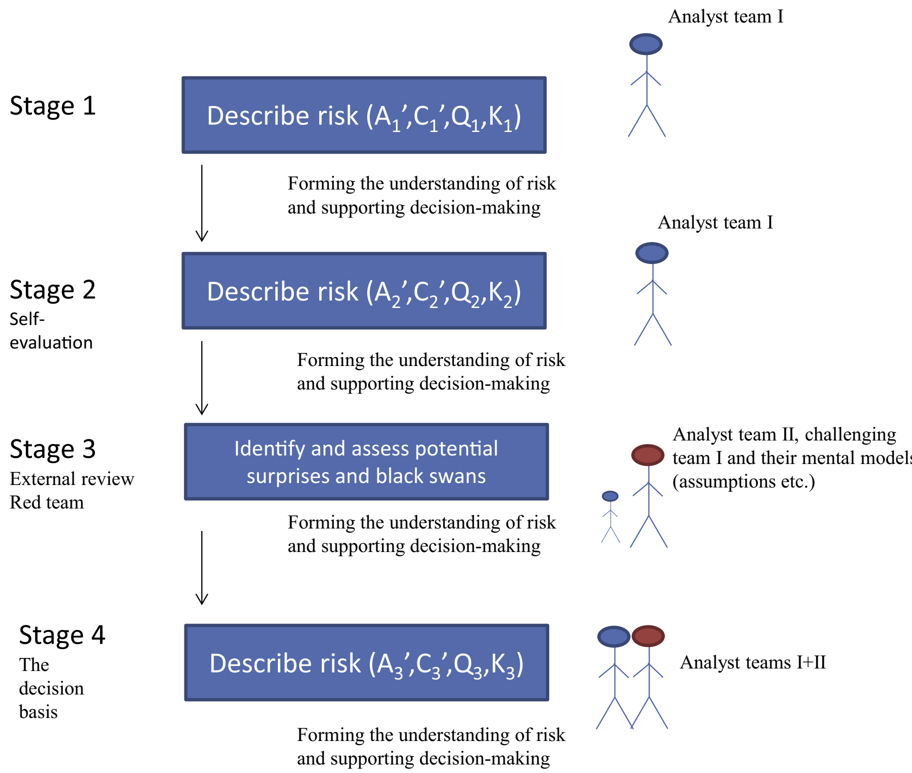

Fig. 1. The four stages of the two-team risk assessment approach.

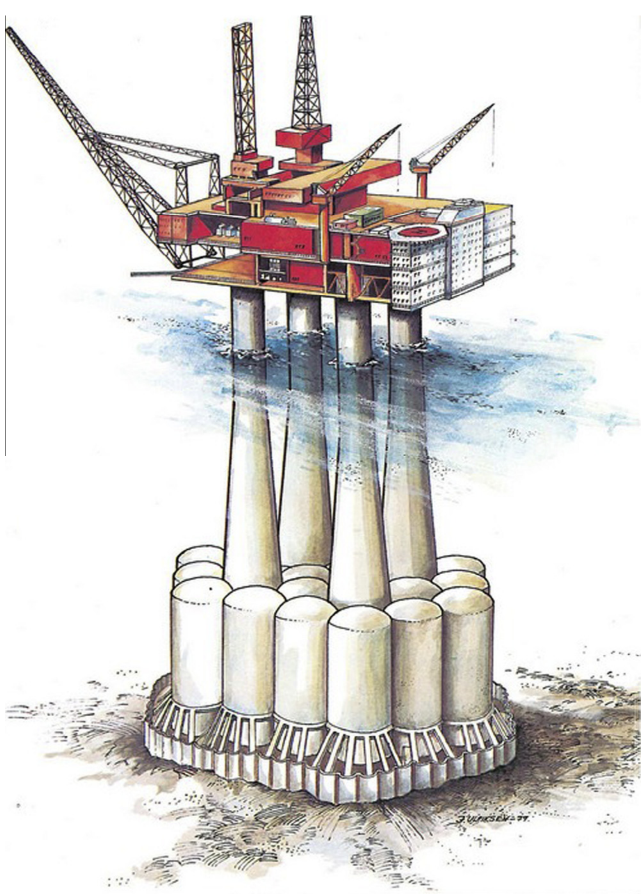

Fig. 2. Offshore oil and gas installation standing on four concrete legs (Ulriksen, 1979).

under pressure. Two operators had just finished cutting through the planned pipe bend section using a saw connected to the hot tap machine. Next, they performed a brushing operation to clean the inside of the pipe before inserting a plug to block the hydrocarbons from flowing. During the brushing operation, a critical component on the hot tap machine for stabilising the saw fell out. This created an opening between the pipe and the outside, resulting in a large flow of oil pouring out on the inside of the contained area of the passageway shaft.

The evaporation of hydrocarbon gas from the leaked-out oil created an explosive atmosphere inside the shaft. The 217 persons on board the installation were now exposed to a potential explosion and fire. The crew initiated a set of response actions, the most important ones that were directed at the leak source being: (i) using deluge to reduce the level of gas in the shaft, (ii) lowering the pressure in the system, (iii) pumping water into the pipe, and (iv) finally refitting the critical component that fell out of the hot tap machine. The oil leak lasted for about 7.5 h, and the volume of the oil that leaked out in the shaft was approximately 156 m^3. No one was injured during the incident.

The Petroleum Safety Authority Norway (PSA-N) initiated an investigation of this incident, and in the final report (PSA-N, 2008) they pointed to poor understanding of risk among the involved personnel as a main cause. This poor understanding was a result of several issues, including:

- A hot tap machine previously used to perform operations on straight pipe sections had been modified to enable cutting through pipe bend sections. A thorough quality check of the new hot tap machine had not been performed (i.e. a technical risk assessment), and some of the personnel lacked the necessary competence to operate the machine.
- It was assumed that hardly any gas would evaporate from a possible oil leak because the medium was stabilised oil. An explosive atmosphere would thus not be attained inside the

shaft. On this basis a specific emergency response plan for handling such a situation had not been developed, and the measures and actions that were taken that successfully resolved the actual incident were improvised by experienced personnel as the incident progressed.
- A precondition for the operation made during the onshore planning, to reduce pressure in the system during the operation, was not observed offshore, without the associated risk being assessed and accepted, and without implementing compensating measures.
- Experience and learning from similar incidents were not considered (several similar incidents had previously occurred).
- Some of the regular personnel working on the installation, who had extensive knowledge and experience relevant for the operation, did not attend the SJA group meeting.

An SJA group meeting was arranged on the platform as part of the preparation for this modification job. The Norwegian Oil and Gas Association has developed some recommended guidelines for performing an SJA (Norwegian Oil and Gas, 2011). These guidelines recommend, among other things, performing assessments of the identified hazards related to the different steps of the operation using a risk matrix, and by assigning scores of the likelihood and the severity (consequence) of the hazard.

According to these guidelines an SJA is a qualitative risk assessment method used by personnel on site offshore to assess risk associated with a particular job in order to decide upon the precautionary and contingency measures that should be taken to reduce risk (Botnevik et al., 2004; Norwegian Oil and Gas, 2011).

Evaluation of the need for an SJA is carried out in all phases of the work from the planning stage through to the actual execution. An SJA is required when risk factors are present or may arise and these factors are not sufficiently identified and controlled through relevant procedures or an approved work permit associated with the actual work. Typical factors to take into account when evaluating the need for an SJA are:

- Is the work described in procedures and routines or does it require exceptions from such procedures or routines?
- Are all risk factors identified and controlled through work permits?
- Has this type of work been prone to incidents/accidents?
- Is the work considered risky, complex or does it involve several disciplines or departments?
- Are new types of equipment or methods used that are not covered by procedures or routines?
- Have the personnel involved experience with the actual work or operation?

The guidelines state that the person acting as the SJA leader should prepare for the SJA meeting by gathering information, drawings, previous experience and any available risk analyses for the actual operation, evaluate if there are special requirements or preconditions for the work, and call in relevant personnel to attend the SJA meeting. During the SJA meeting, the actual risk assessment is being carried out.

The personnel to attend the SJA meeting are those who are part of or influenced by the current work. This makes the SJA an arena for communication and information sharing. Safety delegates and personnel with relevant skills should also attend. It is highlighted in the guidelines that it is important to take previous experience into consideration by reviewing and analysing the gathered background information and input from the attendants at the meeting. All the results from the SJA should be documented in an SJA form, which covers the following key columns: basic steps, hazards/cause, potential consequences and measures and person responsible, and is the total risk acceptable – yes or no?

The first stage of the SJA meeting is to break down the operation into basic steps, allowing each step and sequence of the work to be understood by the involved personnel. Next, risk factors and hazards are identified for each step, and the likelihood and severity of associated consequences are assessed. On the basis of this assessment, risk-reducing measures are chosen that eliminate or control the hazards. Finally, an evaluation and acceptance of the remaining risk are performed (Botnevik et al., 2004). The guideline suggests using a risk matrix as assistance when performing the risk tolerability assessment (see example of a risk matrix in Fig. 7).

In the case study the PSA-N investigation report, on which the present description of the case is largely based, highlights that such a risk assessment, with respect to the oil leak hazard in the planning of this critical operation, was not conducted:

> *"The likelihood of, consequence of or measures to handle a major leak of hydrocarbon oil or gas in the shaft were not evaluated as part of the project development – for example during Safeop (comment: form of HAZOP analysis adopted for assessing operational risk), constructability analysis or SJA. This indicates a lack of understanding of risk or deficient system knowledge on the part of the technical personnel involved."*

In the next section we look into the adjusted risk assessment for critical operations, focusing on the SJA, in line with the approach presented in Section 2. We will use the preparation phase of the above critical operation to illustrate the approach.

3.2. Analysis

Stage 1 could be performed as described in the recommended guideline from the Norwegian Oil and Gas Association (2011). As mentioned in the previous section a traditional SJA comprises basically of five stages:

1. Break down the work activity into basic steps, allowing each step and the sequence of the work to be understood by the involved personnel.
2. Identify the risk factors and hazards of each step.
3. Evaluate the likelihood and severity of the consequences.
4. Identify measures that eliminate or control the hazards.
5. Evaluate and accept the remaining risk.

To be in line with the adjusted risk assessment notations introduced in Section 2, we will in the following denote the members of the SJA group meeting as team I, and the actual group meeting of a traditional SJA as **Stage 1**. In this first stage of the adjusted SJA, the potential hazards for each individual task of the operation are discussed, and an assessment for each of these is conducted. A common way of assisting in performing this assessment and for presenting the risk events and prioritising compensating measures is to use a risk matrix, as shown in Fig. 3.

We restrict our attention to risk associated with an oil leak. The risk from an oil leak was not considered in the real SJA. An oil leak could clearly occur, so the reason for not including this in the SJA must either be an omission or that the risk was assessed negligible and therefore not included in the operation planning. For the sake of presentation we will say that the latter was the case, and use the following as the risk description for the oil leak scenario S_1:

A_1': the hot tap machine does not work according to design, resulting in an unintentional opening between the pipe and the passageway shaft.
C_1': minor oil leak inside the passageway shaft.

	Probability		
Consequence	Low	Medium	High
High			
Medium			
Low	● S_1		

Fig. 3. Consequence and probability score of Scenario S_1 after Stage 1 of the adjusted SJA.

Q_1: low probability.
K_1: reduced pressure inside the pipe system, hardly any evaporation will occur from the medium inside the pipe (stabilised oil).

In **Stage 1** of the adjusted SJA, based on this background knowledge, team I decides to put the oil leak scenario S_1 in the low probability and low consequence area of the risk matrix (see Fig. 3).

In the next **Stage 2**, team I performs a self-evaluation of the risk description in Stage 1. The focus is on the rationale for the risk description from Stage 1, highlighting the strength of knowledge of K_1. Two methods to assess this strength of knowledge are presented by Aven (2013) – a coarse qualitative method and a more detailed semi-quantitative method. Here we have limited ourselves to the first one, which is based on Flage and Aven (2009). In this method, the knowledge is weak if one or more of these conditions are true:

(a) The assumptions made represent strong simplifications.
(b) Data/information are non-existent or highly unreliable/irrelevant.
(c) There is strong disagreement among experts.
(d) The phenomena involved are poorly understood, models are non-existent or known/believed to give poor predictions.

If, on the other hand, all (whenever they are relevant) of the following conditions are met, the knowledge is considered strong:

(s1) The assumptions made are seen as very reasonable.
(s2) Large amount of reliable and relevant data/information are available.
(s3) There is broad agreement among experts.
(s4) The phenomena involved are well understood; the models used are known to give predictions with the required accuracy.

Cases in between are classified as having a medium strength of knowledge.

A simplified version of these criteria is obtained by using the same score for strong but give the medium and weak scores for a suitable number of conditions not met, for example medium if one or two of the conditions (s1)–(s4) are not met and the score weak otherwise, i.e. when three or four of the conditions are not met.

The strength is illustrated in the risk matrix by coloured events: red, yellow or green, depending on whether the background knowledge is considered to be weak, medium or strong, respectively. In our leakage example, we assume that an assessment of the strength of the knowledge was performed as described above and the result was as shown in Fig. 4. During the assessment, team I identifies an unclarified assumption: that the pressure inside the pipe is reduced during the work. The group evaluates the above criteria and decides to assign a medium (yellow) score for the strength of background knowledge.

	Probability		
Consequence	Low	Medium	High
High			
Medium			
Low	● S_1		

Fig. 4. Consequence, probability and strength of knowledge score of Scenario S_1 after Stage 2 of the adjusted SJA.

Moving on to **Stage 3**, a new analysis team II is introduced. Since this is an offshore facility, all competent and relevant personnel for the operations are involved in the first analysis team. Team II is therefore located onshore, and all necessary communication with the offshore facility is performed by the use of technical equipment such as telephone, video conference and email. The members of team II have experience from similar operations and technical expertise of relevance on the form of critical operation in question. In Stage 3, team II questions and challenges the risk description developed by team I, focusing on identifying and assessing potential surprises, acting as a devil's advocate.

Based on previous experience and knowledge about similar oil leak incidents, team II questions the assumption that a leak of stabilised oil would not result in substantial gas evaporating. On the basis of their knowledge, they are confident that this assumption is wrong, and that hydrocarbon gas in fact would evaporate extensively from oil leaked out in the passageway shaft. The development of hydrocarbon gas in the passageway shaft had until now in the planning of the operation not been considered relevant.

Finally, in **Stage 4** the two analysis teams develop a joint risk description. In our case there is now an evident lack of agreement among the experts (question 3 above) concerning the possibility of gas evaporating in the passageway shaft from an oil leak. This further reduces the strength of knowledge supporting the risk assessment, and it is decided to set the strength of knowledge score to low (colour red in the risk matrix). The two analysis groups agree that the consequence category should be changed to high. Fig. 5 now illustrates the updated risk matrix after the final stage of the adjusted SJA.

We have now examined all four stages of the adjusted SJA for the oil spill example. In the next section we will discuss how the process and the results provided by the adjusted SJA can be applied in practical decision-making.

4. Discussion

Stage 1 of the adjusted SJA presented in this paper is to a large extent based on the traditional SJA, while new aspects are introduced in the last three stages of the adjusted SJA. One new aspect is highlighting the strength of knowledge supporting the SJA, and how the strength of knowledge can affect the risk acceptance judgement.

In traditional thinking (e.g. AS/NZS, 2004; ISO, 2009; NORSOK, 2010; Norwegian Oil and Gas, 2011), a risk acceptance judgement is often carried out as a part of a probability based risk assessment. This risk acceptance judgement can be incorporated in probability based risk matrices (see Fig. 6), in which an event based on its consequence and probability score is judged as either acceptable (green)[1], tolerable if measures are implemented (orange) or unacceptable (red).

In line with the ideas of Aven (2013), the above approach can be adjusted to also incorporate the strength of knowledge considerations; see Fig. 7. Three dimensions of risk are thus captured in Fig. 7: probability and consequence (represented by the probability

[1] For interpretation of color in Fig. 6, the reader is referred to the web version of this article.

	Probability		
Consequence	Low	Medium	High
High	● S_1		
Medium			
Low			

Fig. 5. Consequence, probability and strength of knowledge score of Scenario S_1 after Stage 4 of the adjusted SJA.

based risk judgement on the vertical axis) and the strength of knowledge supporting the probability based risk assessment (the horizontal axis). According to this line of thinking, if the strength of knowledge is weak, risk should be judged as unacceptable even if the probability–consequence assignments indicate tolerable or acceptable risk.

Let us consider an example from the oil spill case presented in Section 3.2. Suppose the risk is judged as acceptable in the initial SJA (Stage 1 of the adjusted SJA) based on traditional probability based thinking. As demonstrated, the final three stages of the adjusted SJA helped in gaining a wider understanding of important risk issues better reflecting uncertainties and the unforeseen. This resulted in an increased awareness about the actual weak knowledge supporting the initial probability based risk assessment, and the result could be that the risk is judged as unacceptable.

The oil spill event can be seen as an unforeseen event, but it would be wrong to call its occurrence a complete surprise. Its possible occurrence is known by other persons, groups or communities. The adjusted SJA is a way of meeting the challenge posed by this type of risk event by improving the capability to identify these events, and by improving the communication by facilitating a transfer of knowledge between relevant groups, i.e. the inclusion of a second analysis team with relevant knowledge and experience.

The adjusted assessment approach is also a tool for dealing with potential surprises of a different type, namely, extreme events that occur which were not believed to occur due to probabilities judged as negligible. The operating team may disregard events because they are considered to have a very small probability. Yet they may occur. Probability assignments are based on some knowledge, and, as commented many times already, this knowledge may be more or less strong, and needs to be scrutinised. This is what team II is doing when they address the assumptions and beliefs of team I. They look for potential surprises relative to the explanations and hypotheses of the first analysis team.

The oil spill case showed two important contributions made by adding an assessment of the strength of knowledge. The first is creating a basic awareness among the analysis teams and personnel about how the actual level of knowledge can affect the risk. The second concerns considerations of the practical implications that this can have on the risk related to the operation, and how to best respond by implementing sound risk reducing measures.

An objective of the traditional SJA is to identify appropriate measures to reduce risk to a tolerable level. Measures are only (at least consciously) able to deal with issues that have been uncovered during the SJA. If the SJA fails to reveal important issues that can affect the risk, it is obviously not possible to choose measures that are pinpointed to deal with these issues. The improved understanding of risk provided by the process and the outcome of the adjusted SJA can be very useful for identifying appropriate measures.

For critical operations with a major accident potential, we recommend carrying out all four stages of the adjusted SJA. In other cases, only the first two stages should be conducted, but care has to be shown in these judgments. If we consider the oil leak case discussed above, the critical operation was initially not regarded as having a major accident potential. A main reason for failing to identify this potential was that the weak knowledge supporting the risk assessments during planning was not appropriately considered.

A way to deal with this challenge of not being able to identify the major accident risk contributors is to conduct an adjusted risk assessment earlier in the planning phase, in line with the general ideas presented in Section 2. These ideas can also be applied for other forms of risk assessments, not only SJA. By conducting an adjusted risk assessment in the planning phase, there will be an increased chance of identifying the unknown known types of risk.

Petroleum Safety Authority Norway (PSA-N) has recently introduced a new definition of risk (risk is the consequences of the activity with associated uncertainties), which intends to give a stronger focus on the knowledge aspects of risk (PSA-N, 2015). The analysis method presented in this paper can be seen as a tool aiming at meeting some of the challenges raised by PSA-N. Real life testing is however required to gain experience with the method

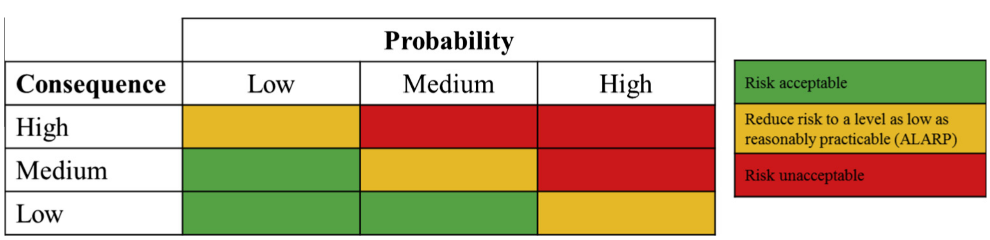

Fig. 6. Example of a risk matrix with tolerability judgements.

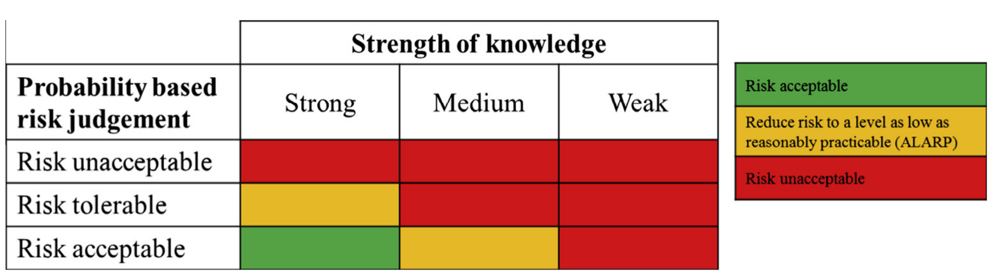

Fig. 7. Example of a risk matrix when strength of knowledge is taken into account (based on Aven, 2013).

and establish procedures that make the method possible to use in practical settings.

The use of red teams to review the initial analysis is not new, and it has also similarities with peer review processes that are applied in many other contexts, for example project risk management (Cooper et al., 2005). However, these review processes are not based on a risk framework highlighting the strength of knowledge.

5. Summary and conclusions

In this paper we have presented a general method for conducting an "adjusted risk assessment" for critical operations, which better reflects uncertainties and the unforeseen compared to current practice. A case study based on a real oil spill incident that occurred on a Norwegian offshore platform has been used to demonstrate the approach.

The adjusted risk assessment includes a second, independent analysis team. Their job is to act as a red team, and they should for example argue for the occurrence of events with assigned negligible probabilities, search for unknown knowns (events that are known by others but not team I), and check how signals and warnings have been reflected. Members of team II should not have been involved in the initial planning of the operation, to be able to provide a new set of eyes.

A key aspect of the adjusted risk assessment is to bring forward and question the effect that the knowledge (or lack of knowledge) supporting the risk assessment can have on the assigned risk. Both analysis teams are used for this purpose. The first analysis team reviews the rationale behind the initial risk judgements and the knowledge supporting it. The second analysis team goes one step further and questions the arguments used for the identified risk events, in particular the assumptions supporting the judgements made. A key focus is on those events with an initial assigned low probability.

Through the increased focus on the knowledge dimension, the aim is to improve the understanding of relevant risk issues, increase risk awareness and avoid potential surprises. Using the adjusted risk assessment approach does not provide a guarantee of identifying all types of potential surprising events. Having in mind the many near accidents we have experienced in the oil and gas industry in recent years due to a poor understanding of risk, we are, however, confident that the present approach with its focus on knowledge and uncertainties represents a useful supplement to existing tools for assessing this type of risk. Current practice does not adequately address the unforeseen and surprise dimensions.

As highlighted in the previous section, testing of the method is needed for practical implementation. Work is now conducted in the industry to better incorporate the knowledge aspects of risk, and even a reduced version of the method would represent an improvement to this end by addressing the triplet consequences, probability and strength of knowledge judgments, and not only the first two. The full version of the method could be resource demanding and it should be used only when the potential consequences are severe. Identifying potential surprises always represents a challenge. The approach presented addresses some topics, and a check list can preferably be used to ensure that the key aspects are covered. The check list should include questions like:

Have key assumptions been identified?
Have the risk related to deviation of these assumptions been assessed?
Have the strength of knowledge been assessed?
Have attempts been made to strengthen the knowledge where it is not considered strong?
Have special measures been implemented to reveal unknown knowns?
Have special efforts been made to check the validity of judgments made where events are not believed to occur because of negligible assessed probability.

Such aspects are to varying degree also addressed in the analyses conducted today, but there is a lack of adequate concepts and structures that encourage and stimulate the discussion. Properly implemented the adjusted SJA can hopefully represent an important contribution to improving the current practice in this area, strengthening the risk management linked to risk aspects concealed in the background knowledge (assumptions) and potential surprises.

Acknowledgments

The authors are grateful to two anonymous reviewers for their useful comments and suggestions to the original version of this paper. The work has been partly funded by the Norwegian Research Council – as a part of the Petromaks 2 programme (Grant number 228335/E30). The support is gratefully acknowledged.

References

AS/NZS, 2004. AS/NZS Handbook 436:2004. Risk management guidelines. Companion to AS/NZS 4360:2004. Standards Australia, Sydney, N.S.W.
Aven, T., 2013. Practical implications of the new risk perspectives. Reliab. Eng. Syst. Safe. 115, 136–145.
Aven, T., Krohn, B.S., 2014. A new perspective on how to understand, assess and manage risk and the unforeseen. Reliab. Eng. Syst. Safe. 121, 1–10.
Botnevik, R., Berge, O., Sklet, S., 2004. Standardised procedures for work permits and safe job analysis on the Norwegian Continental Shelf. In: The Seventh SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Society of Petroleum Engineers Inc., 29–31 March 2004, Calgary, Alberta, Canada.
Cooper, Dale F., Grey, Stephen, Raymond, Geoffrey, Walker, Phil, 2005. Project Risk Management Guidelines Managing Risk in Large Projects and Complex Procurements. Wiley, Chichester.
Flage, R., Aven, T., 2009. Expressing and communicating uncertainty in relation to quantitative risk analysis. Reliab. Risk Anal.: Theor. Applicat. 2 (13), 9–18.
ISO, 2009. Risk Management – Risk Assessment Techniques. International Organization for Standardization, Genève.
Leistad, G.H., Bradley, A.R., 2009. Is the focus too low on issues that have a potential that can lead to a major incident? SPE 123861. Paper presented at SPE Offshore Europe Oil and Gas Conference Aberdeen, 8–11 September 2009.
Meyer, T., Reniers, G., 2013. Engineering Risk Management. De Gruyter Graduate, Berlin.
NORSOK, 2010. NORSOK STANDARD Z-013 Risk and emergency preparedness assessment, third ed., Standard Norge.
Norwegian Oil and Gas, 2011. Norwegian Oil and Gas recommended guidelines for Common Model for Safe Job Analyses (SJA). Revision no: 3. Date revised: 11.07.11, Norwegian Oil and Gas.
PSA-N, 2008. Investigation of incident hydrocarbon leak in utility shaft on Statfjord A 24 May 2008. Activity number 001037004. Unofficial translation, Norwegian Petroleum Safety Authority.
PSA-N, 2012. Safety status & signals, Petroleum Safety Authority Norway. ISSN: 1890-4491.
PSA-N, 2015. <http://www.ptil.no/publikasjoner/SafetyStatusandSignals2014/HTML/files/assets/common/downloads/page0037.pdf> (accessed 15.05.15).
StatoilHydro, 2008. Granskingsrapport: Oljelekkasje i utstyrskaft på Statfjord A 24.5.08 (ENG: Corporate Audit: Oil spill in the utility shaft on Statfjord A 24.5.08).
Ulriksen, J., 1979. "Drawing of the Statfjord B platform" (retrieved 15.11.13) <http://www.norskolje.museum.no/modules/module_123/proxy.asp?D=2&C=230&I=2235>.
Vinnem, J.E., 2014. Offshore Risk Assessment. Springer Verlag, London.