Effective Updates of Risk Assessments in Operational Phase

David Volent Lindberg, Andreas Hafver, Hilde Weir, Kjellaug Litland, Erik Sælen
DNV GL, Norway

Andreas Falck
University of Stavanger and DNV GL, Norway

ABSTRACT: For any hazardous operation, subject to potential major accidents, the operator needs to have an updated risk picture. The purpose of risk assessments in the operational phase is to provide risk-based support to operational decisions, which differs in nature from decisions made in earlier phases. In operation, decisions must be made regarding how activities should be coordinated and prioritized, and this will be influenced by the changing risk picture.

It is common practice to conduct new risk assessments at regular intervals, in order to maintain an updated risk picture. However, this is both expensive and time-consuming, and much of the basis for the original risk assessment is expected to remain valid. A more effective approach would be to review the existing QRA and only update only those parts where the premises underlying the existing assessment no longer hold.

In this paper we propose a methodology for identifying the aspects of a risk assessment that require updating.

Step I in this approach is to list the changes that have occurred since the previous risk assessment, and to classify them into three types: The first type is physical (real) changes, which may have a direct impact on risk. The second type is changes in knowledge, which do not directly influence risk, but which may influence how we assess the risk. The third type of changes is changes in context (e.g., changes in the regulatory regime and requirements), which affect the extent to which risk is tolerated.

Step II in our procedure is to evaluate the effects that the changes identified in Step I have on the risk assessment. Aspects of the risk assessment that are considered in this regard include the risk assessment scope and the methodologies, models and model inputs used in the original risk assessment. For each aspect, the effect of changes is evaluated both with respect to safety (i.e., changes in risk or risk tolerance) and with respect to how they affect our confidence in the existing risk assessment (i.e., changes in knowledge that could alter the judgments made in the existing risk assessment). A decision matrix is presented which may be used to determine if and how a particular aspect should be updated, based on the combined effects on safety and confidence.

The proposed approach may reduce costs for updating risk assessments in the operational phase, and may also allow for more frequent updates. The latter will ensure a more updated risk picture on which to base operational decisions, and this would have positive effects on safety.

Key words: risk assessment, operational phase, gap analysis, oil and gas.

1 BACKGROUND AND OBJECTIVES

For hazardous operations and installations subject to potential major accidents, quantitative risk assessments (QRA) are typically performed in the early project phases. This serves to inform decision makers regarding the impact of various design solutions on the future safety on the installation and to ensure an acceptable level of risk. Once in operation, the same QRA is used as a basis for operational decisions regarding how activities should be coordinated and prioritized. However, risk during operations is impacted by potential modifications to the facilities and changes in hazards. In addition, judgments regarding safety may be influenced by new knowledge acquired during operation, as well as changes in regulations and requirements. Updating QRAs in the operational phase is a way to ensure that operational decisions are properly risk-informed.

Many operators exert their operator responsibility by conducting a full update of the existing QRA on a regular basis (5 years is common in Norway), following the same approach as during the design phase [1].

However, although there may be degradation of systems, modifications to facilities or changes in operational conditions, much of the study basis from the existing QRA is expected to remain valid. Hence, a complete update of all parts of the QRA may not be necessary, and resources could be better spent by focusing on changes that either have significant impact on safety, or which lead to reduced confidence in the existing QRA. The need for more efficient QRA updates is gaining recognition in the industry, in a time with increased pressure on costs. In addition, a more efficient approach for updating QRAs could allow more frequent updates, for instance once per year, providing operators with a more updated risk picture and better decision support.

Falck, Flage & Aven [1] outline an approach for effective updates of QRAs in three phases, as described below and illustrated in Figure 1.

- **Initiation phase:** The purpose of the first phase is to check whether the current QRA basis is reflecting the operational and technical conditions that the facility operates under and to identify aspects or hazards that need to be (re)assessed.
- **Assessment phase:** The purpose of the second phase is to update the parts identified in the first phase, to identify important risk drivers, and to link these towards operational controllable parameters.
- **Implementation phase:** The purpose of the third phase is to implement and communicate the findings from the second phase within the operating organization.

In this paper, we focus on the initiation phase of the framework above. We present a procedure for establishing the validity of the existing QRA through identifying critical gaps. This serves as a screening process, to avoid unnecessary updating in the assessment phase of aspects where changes have little impact on the conclusions of the existing QRA.

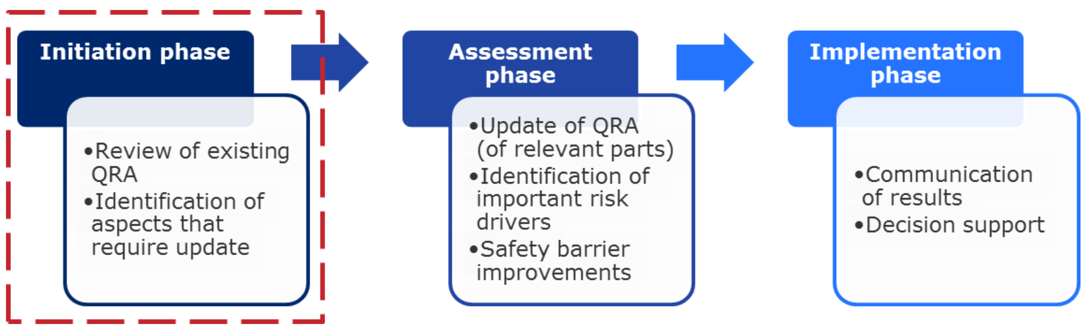

Figure 1. Approach for effective updating of the QRA in the operational phase, as described in [1]. This paper focuses on the initiation phase (highlighted in the red box).

2 RISK ASSESSMENT METHODOLOGY

In order to describe a methodology for updating QRAs in the operational phase, it is important to understand what the objective of conducting a risk assessment is. This, in turn, requires an understanding of what risk is.

Most QRAs make use of probabilistic models, and the results of a risk assessment are typically communicated to clients and stakeholders in terms of some probabilistic risk measures. Examples of such risk measures include expected consequences for an individual or a particular population, f-N curves (e.g., depicting the probability/frequency of events with N or more fatalities), and risk matrices (where accident events are sorted according to likelihood of occurrence along one direction and corresponding consequence in the other direction). Risk acceptance criteria (RAC) (i.e. criteria for what level of risk is considered acceptable) are often defined in terms of such quantitative risk measures, and RACs serve as points of reference when comparing differences in risk across installations, design options or over time.

Despite the wide use of probabilistic risk measures, there is an increasing acknowledgement that risk cannot be fully described in terms of probabilities [2]. As a result, there has been a recent shift towards risk being defined in terms of uncertainty rather than probability. For example, the Petroleum Safety Authority Norway defines risk as *"…the consequences of an activity with associated uncertainty"* [3]. Accordingly, a risk assessment is meant to evaluate the consequences of an activity and associated uncertainty, in order to expose the impacts the activity may have on stakeholders and systems, and to provide a basis for informed decision making. However, a risk assessment is always conditional on the risk analysts' knowledge and understanding of the systems and activities under consideration. In particular, choices, simplifications and assumptions are made on three levels during a QRA process [4]:

i) when defining the scope of the risk assessment;
ii) when choosing models and methodologies and making judgments about uncertainty, and;
iii) when selecting which risk measures to present and communicate.

These choices and assumptions may conceal uncertainty, and a set of risk measures is therefore not sufficient to describe the full risk, and may not even be informative with respect to the decisions they are intended to inform. The relationship between risk and risk measures is illustrated schematically in Figure 2.

The implication of the above is that, in addition to the conclusions, it also matters how conclusions were reached. A comprehensive risk assessment must contain an evaluation of the assumptions and choices made and whether deviations from (or violations of) these could have significant impacts on the results [2]. An evaluation of the knowledge base that underlies the QRA provides information about the robustness of the risk assessment, i.e. how confident the user can be in the results. Such information is crucial to enable fully risk-informed decisions.

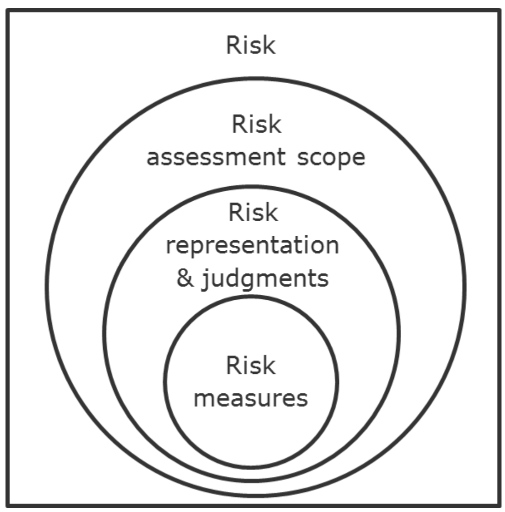

Figure 2. Risk (square box) refers to the consequences of an activity with associated uncertainty, and exists independently of the risk assessment. A risk assessment is the risk analysts' description of risk, and relies on a series of assumption and choices, which may conceal uncertainty. This is illustrated by the circles, where each level only captures a subset of the level above. Note that the relative position and overlap of the circles would generally differ for different risk analysts, hence it is important that the assessment is transparent, to allow stakeholders to trace how conclusions were reached [4].

3 APPROACH FOR IDENTIFYING CRITICAL GAPS

The purpose of the initiation phase (in the red box in Figure 1) is to identify changes from the operational and design basis [1], and to evaluate whether these may have an effect on the risk as described by the existing QRA. The aim is to provide a list of the aspects of the QRA that needs to be updated, and to screen out those that do not. For this, we propose a two-step approach, which is described in more detail in the subsections below:

Step I - Identification of changes: Make a list of all changes that have taken place since the previous QRA. This may be considered as an update of the knowledge basis underlying the existing QRA.

Step II - Gap analysis: Review the effect of the changes identified in Step I by performing a gap analysis according to the flow chart in Figure 4, and use the decision matrix in Figure **5** to decide further action.

3.1 Step I - Identification of changes

Step I in our procedure is to list the changes that have occurred since the previous QRA. The rationale behind listing the changes is that the same change may affect several aspects of the QRA. By listing them once, it is possible to refer back to them and avoid repetition when evaluating the need for making updates in Step II, hence making the procedure more efficient.

There are several types of changes that can happen between the design phase and the operational phase. Some changes may affect the risk directly, whereas other changes may have impact on our confidence in the existing risk assessment, without necessarily affecting risk. We suggest the following categorization for classifying changes:

- **Physical changes:** Real changes that directly influence the risk level, i.e. that imply an actual change in the exposure or vulnerability to hazards since the previous QRA. This may include:
  - Modifications to, or degradation of, installations;
  - Changes in processes over time;
  - Changes in operations/activities;
  - Changes in external factors influencing that influence the risk.
- **Changes in knowledge:** Changes that do not imply a real change in the risk level, but which may have implications for how we *assess* the risk and how confident we are in the existing QRA. In particular, change in understanding will affect how we assess the strength-of-knowledge behind our assumptions. Examples of changes in knowledge include:
  - Changes in domain knowledge, i.e., scientific understanding of processes and systems, including models and methodologies, and;
  - Changes in operational knowledge, i.e., experience and data accumulated during operations.
- **Changes in context**: Even in the absence of physical changes or new knowledge, the interpretation and implications of the results of a QRA may be influenced by changes in context. Changes in context do not imply a real change in risk, but may affect our acceptance of risk or determine which types of risks that are most relevant to the decision at hand. Examples of changes in context include:
  - Changes in regulations and standards;
  - Changes in stakeholder perceptions and requirements.

Note that the first and third types of changes can affect *safety*, which is defined by ISO/IEC as "*freedom from risk which is not tolerable*" [5]. More specifically, physical changes may alter the risk, whereas changes in context may alter the acceptance of or attitude to risk. On the other hand, changes in knowledge do not directly impact on safety, but can affect our confidence in the existing QRA.

Using the above classification as a guideline, a list can be made of the changes that have occurred since the previous QRA. TABLE I shows an example of how this may be done. Assigning codes to the changes allows for efficient referencing in step II.

TABLE I - Examples of changes that may occur during the operational phase, identified in Step I.

Physical changes	
P1	Ship traffic in area is up by 100%.
P2	Well pressure is reduced by 30%.
Changes in knowledge	
K1	A new improved gas dispersion model shows that the old model underestimated dispersion time.
K2	Records show that the number of hot work hours has been only 60% of the estimate in the QRA.
Changes in context	
C1	New, stricter risk acceptance criteria have been set for safety functions.
C2	Regulators have expressed concern that ship collision risk has not been assessed.

3.2 *Step II - Gap analysis*

The objective of this step is to evaluate how the changes identified in Step I impact the QRA, and to identify which aspects of the QRA that must be updated. Aspects of the existing QRA that are affected by changes are called gaps, and critical gaps are gaps which could have significant influence on the results of the risk assessment. Critical gaps must be addressed in the assessment phase, whereas gaps that are found to not be critical, or aspects for which there are no gaps, can be left out and need no update. This step thus serves as a screening process.

Figure 2 suggests a systematic approach to decide which aspects of the QRA to consider in the gap analysis: It highlights the choices and assumption that have been made in the existing QRA, and gaps can be identified by asking whether these choices and assumptions are valid or justified in light of the changes identified in Step I. Figure 3 suggests a possible sequence for conducting the gap assessment, as described in more detail below:

- **Scope and objectives***:* If something has changed that impacts the scope or objective of the QRA, considerable updates may be necessary. For example, if a hazard that is now found to be relevant was not included in the existing QRA, then a new assessment of this hazard should be conducted in the assessment phase (Figure 1). Similarly, if a hazard no longer exists, it could simply be removed from the QRA, and further questions related to how it was modelled previously are no longer relevant.
- **Models and methodology:** Often, a QRA is separated into sections addressing various hazards with a separate model. It then makes sense to go through the models and methodology for each hazard sequentially. The essential question to consider is whether or not there exists new knowledge or new models that would allow better modelling of the particular hazard. It is only meaningful to ask questions about models and methodologies for hazards that were already included in the existing QRA.
- **Model inputs:** If there are no critical gaps related to the models and methodologies themselves, one should proceed by assessing potential gaps related to model inputs. The essential questions to ask in this regard are whether or not the input values or distributions used in the existing QRA are still valid or justified.

Following the above sequence can help ensure that all aspects of the QRA are covered in an efficient way in the gap analysis.

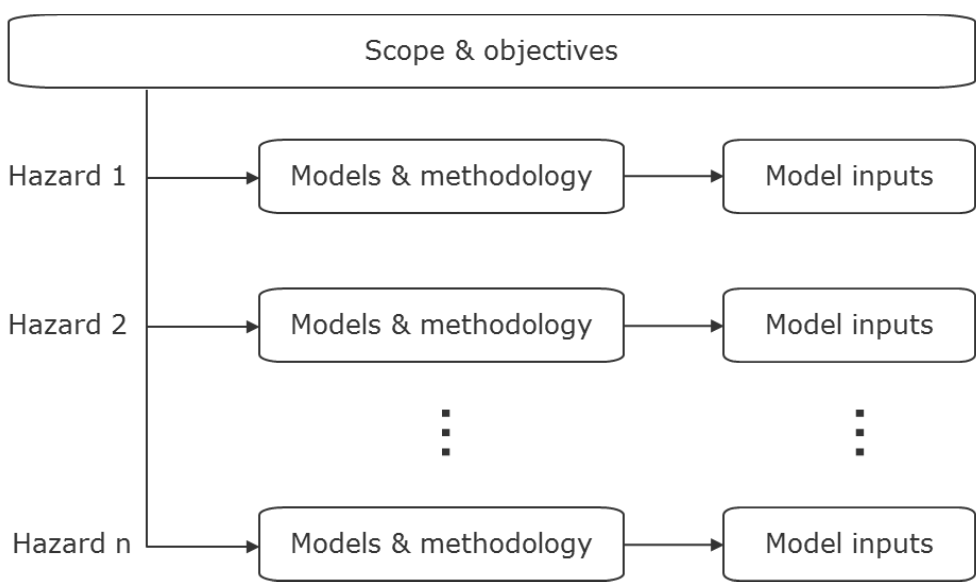

Figure 3. A systematic approach for identifying aspects of an existing QRA that requires updates; i) first assess the overall scope and objectives and then, for each hazard in turn, assess ii) the models and methodology used and iii) the model inputs.

To identify if there is a critical gap related to a particular aspect of a QRA, we propose the following methodology, which is summarized in the flow chart in Figure 4:

1) **Is there a gap?**

Changes identified in Step I which are relevant to the aspect under consideration should be listed. By relevant, we here mean that the change either contributes to more uncertainty related to this aspect, *and/or* that there are changes that would have resulted in different choices and judgments with respect to this particular aspect if a new risk assessment was performed today (e.g., a different model would have been selected, or a different value or distribution would have been used for a model input). The latter could be either due to actual physical changes or due to new knowledge.

- If there are no relevant changes, the answer is "NO".
- If there is at least one relevant change, the answer is "YES". Proceed with part 2).

2) **Is the gap critical?**

A gap may be critical for different reasons, as described in Section 3.1: The relevant changes identified in the previous step may impact the risk, the tolerability for risk or the confidence in the existing risk assessment. The questions below, together with the matrix in Figure 5, may be used to determine whether a gap is critical or not:

- **What is the effect of the gap on safety?**
  This is an evaluation of the implications of physical changes and changes in context.
  - **"Improved":** Physical changes are expected to have a risk reducing effect *and/or* changes in context cause us to judge the risk as more acceptable.
  - **"Unchanged":** There are no relevant physical changes *and* no relevant changes in context.
  - **"Slightly reduced":** Physical changes are expected to increase the risk *and/or* changes in context are expected to reduce the acceptance of risk, however the effect is not expected to have significant influence on the conclusions reached in the existing QRA regarding safety.
  - **"Significantly reduced":** Physical changes could lead to an increase in risk *and/or* changes in context could lead to a reduction in risk acceptance, to an extent that could potentially alter the conclusions reached in the existing QRA regarding safety.
- **What is the effect of the gap on our confidence in the existing QRA?**
  This is an evaluation of changes in knowledge.
  - **"Improved/unchanged":** There is no new relevant knowledge, *or* the new knowledge lends support to, or does not affect, judgments made in the existing QRA.
  - **"Slightly reduced":** There is new knowledge, which if known at the time of the previous QRA, would have resulted in slightly different judgments *or* new knowledge creates more uncertainty around the aspect under consideration, but is not likely to have caused different choices or assumptions.
  - **"Significantly reduced":** There is new knowledge which invalidates previous assumptions, *or* there is knowledge which, if known at the time of the previous QRA, would have resulted in significantly different judgments.

Based on the evaluations above, various aspects are classified as green, yellow or red. For aspects ending up in the green box, there are either no relevant changes or changes are judged to not alter conclusions, hence no update is necessary. For aspects ending up in the yellow box, the changes are not expected to alter conclusions of the existing risk assessment. Rather than a full update, a qualitative evaluation is recommended, to assess how robust the existing QRA is with respect to deviations in the particular aspect under consideration. For this, the approach proposed by Berner & Flage [6] could be applied. For aspects ending up in the red box, an update is judged to be necessary, as the conclusions of the risk assessment may potentially change due to the changes since the previous QRA.

The outcome of the above assessments is that many aspects will be screened out, i.e. ending up in the green box, and the resulting list of critical and potentially critical gaps can be used as basis for an efficient update of the QRA in the assessment phase. A few examples of how the scheme may be applied are shown in TABLE II.

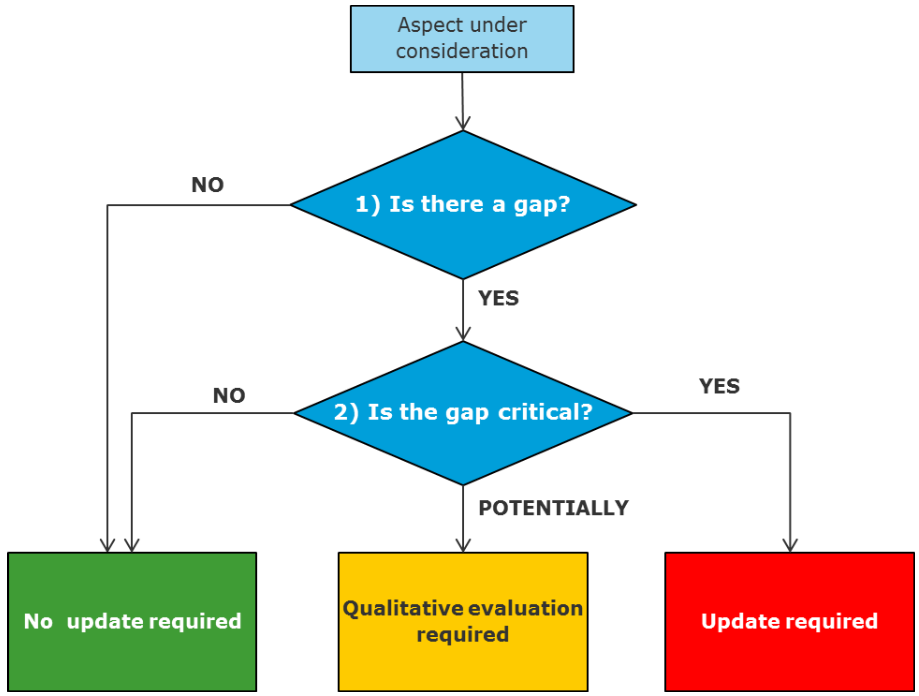

Figure 4. Flowchart for gap analysis performed in Step II.

		Effect on safety			
		Improved	Unchanged	Slightly reduced	Significantly reduced
Effect on confidence	Improved/ unchanged	NO	NO	POTENTIALLY	YES
	Slightly reduced	NO	NO	POTENTIALLY	YES
	Significantly reduced	NO	POTENTIALLY	YES	YES

Figure 5. Matrix used to decide whether a gap is critical or not in the last step of the flow chart in Figure 4.

TABLE II – Examples of using the gap assessment methodology according to the flow chart in Figure 4 and the decision matrix in Figure 5. Codes for changes refer to examples in TABLE I.

Aspect	Is there a gap?	Effect on safety	Effect on confidence	Action
Overall risk assessment scope	Relevant changes: P1 C2	**Significantly reduced** A quantitative assessment for ship collisions was not performed previously, and P1 implies an increase in risk. C2 indicates a change towards lower risk acceptance.	**Improved/unchanged** Our understanding/ awareness of hazards has not changed	**Update required** Ship collision risk must be assessed.
Blow out risk	Relevant changes: P2	**Improved** P2 implies that blow outs are less likely.	**Unchanged** Our understanding/ awareness of blow out risk has not changed.	**No update required**
Ignition probability	Relevant changes: K1,K2	**Unchanged** There is no reason to believe that the risk/safety has actually changed since the previous QRA	**Significantly reduced** Although K2 indicates that the current QRA is conservative, the combined effects of K1 and K2 are uncertain, and ignition probability has significant impact on the assessed risk.	**Qualitative evaluation required** An assessment should be made of the robustness of the existing QRA to changes in the ignition probability

4 CONCLUSIONS

In this paper we have presented a procedure for reviewing QRAs in the operational phase. More specifically, the focus has been on the initiation phase, where critical gaps are identified to determine which parts of a QRA that needs to be updated, so that a full update of the QRA can be avoided.

Step I of our approach is to identify changes that have occurred since the previous QRA and to classify them. We distinguish between physical changes (affecting risk), changes in context (affecting acceptance of risk) and new knowledge (which may have influence on judgments made in the existing risk assessment). Of these, the first two types of changes affect our assessment of safety, understood as freedom from unacceptable risk, whereas the last type affects our confidence in the QRA.

In Step II, we follow a sequential approach to identify aspects of a QRA that need to be considered for updating. This approach is based on identifying critical assumptions and choices made during the original QRA. Overall aspects of the existing QRA, such as the assessment scope, are considered first, before evaluating more detailed aspects, such as models, methodologies and model inputs used. This structured approach ensures that all aspects of the QRA are covered, and enables an efficient workflow.

Gap analysis is used to evaluate if a particular aspect of the QRA needs updating. A gap is defined to exist if any changes have occurred that have relevance to the aspect under consideration. To determine if a gap is critical, the effect of the gap on safety and confidence in the existing QRA is evaluated. Both increased risk, reduced acceptance for risk and reduced confidence in the existing QRA are valid reasons to consider updating, and a matrix is used to determine if and how a particular aspect should be updated. Performing this procedure for all aspects of the QRA serves to screen out the aspects that do not require update, and enables a more focused and efficient update of the QRA in the assessment phase (Figure 1). Additional efficiency in Step II can be achieved by assigning codes to the various changes identified in Step I, allowing easy reference to and avoiding repetition of changes that affect many aspects of the QRA.

By following the proposed approach, one may avoid spending unnecessary time and resources on performing a complete update of all hazards in the QRA, whether there have been changes or not. The improved efficiency may also allow updates of QRAs to be conducted more frequently, providing a more updated and better validated risk picture to the operator. This will in turn facilitate better informed decisions and improve safety.

5 REFERENCES

[1] FALCK, A., FLAGE, R., AVEN, T., “Risk Assessment of Oil and Gas Facilities During Operational Phase”, *In Proceedings of the European Safety and Reliability Conference (ESREL),* Zürich, Switzerland, 7-10 September 2015, p.59, CRC Press (2015).

[2] AVEN, T., “Practical implications of the new risk perspectives”, Reliability Engineering and System Safety 115, 2013.

[3] “Safety – Status and Signals 2013-2014”, Petroleum Safety Authority Norway (PSA), 2014.

[4] HAFVER, A., LINDBERG, D.V., JAKOPANEC, I., PEDERSEN, F.B., FLAGE, R., AVEN, T., ”Risk – from concept to decision making”, *In Proceedings of the European Safety and Reliability Conference (ESREL)*, Zürich, Switzerland, 7-10 September 2015, p.116, CRC Press (2015).

[5] *ISO/IEC Guide 51:2014*. 2014.

[6] BERNER, C., & FLAGE, R., “Quantitative vs. qualitative treatment of uncertain assumptions in risk assessment”, *In Safety and Reliability: Methodology and Applications*, p.2321-2328. CRC Press (2014).