

# METHODOLOGY FOR INCORPORATING HUMAN AND ORGANIZATIONAL FACTORS IN RISK ANALYSIS FOR OFFSHORE INSTALLATIONS

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This paper presents a methodology for quantitative risk analysis for offshore installations, that incorporates both technical and operational conditions. The basic building blocks of the methodology are barrier block diagrams, event trees, fault trees, and influence diagrams. Barrier block diagrams are used to illustrate the event scenarios and the effect of barrier systems on the scenarios. Event trees are used in the quantitative analysis of the scenarios, while fault trees are used to analyze the performance of the different barrier systems. Influence diagram are used to analyze the effect of risk influencing factors on the initiating events in the event trees and the basic events in the fault trees. The aim of the analysis is to reflect installation specific factors both with respect to technical systems, operational conditions as well as human and organizational factors.

*Keywords:* human and organizational factors, risk analysis, risk influencing factors, barriers

## 1. Introduction

Traditionally, offshore quantitative risk analyses (QRAs) have had a rather crude analysis of barrier performance, emphasizing technical aspects related to consequence reducing

systems. However, recently the Petroleum Safety Authority Norway (PSA) has been focusing on safety barriers and their performance, both in regulations concerning health, safety and environment (Ref. 15) and in their supervisory activities. A strong need for more detailed analyses reflecting operational factors has been identified (Ref. 22), and a research activity “BORA” (Barrier- and Operational Risk Analysis) was initiated.

The aim of the BORA project (Ref. 22) is to perform a detailed and quantitative modeling of barrier performance, including barriers to prevent the occurrence of initiating events as well as barriers to reduce the consequences. Work has been carried out to establish a basic overall structure for barriers and barrier elements, taking as the starting point the following barriers:

- Prevent loss of containment (leak)
- Prevent ignition
- Reduce cloud/emissions
- Prevent escalation
- Prevent fatalities.

One of the challenges in the BORA-project is to carry out a quantitative analysis of risk influencing factors, including both technical and operational conditions. Several methods or models for incorporating organizational factors in quantitative risk analyses are described in the literature, like Manager (Ref. 14), MACHINE (Ref. 6), WPAM (Refs 4,5), SAM (Ref. 13), IRISK (Ref. 2), and ARAMIS (Ref. 10). None of these methods seems to be regularly applied by the industry. However in the BORA project we attempt to adapt ideas from these methods to the offshore industry. The intention is that a BORA analysis shall reflect installation specific factors as far as reasonably practicable, with respect to technical systems as well as human, operational and organizational factors.

The purpose of this paper is to present and discuss the BORA approach for incorporating risk influencing factors (RIFs) in quantitative risk analyses. The basis is the method description of BORA (Ref. 1).

The BORA approach is presented in Section 2, and an example case is used to illustrate the steps in the methodology. Each step in the methodology is discussed in Section 3. Section 4 includes some conclusions and some notes about challenges and further work.

Due to the extensive scope and complexity of the total BORA project, some delimitations and assumptions are made; a) This paper deals primarily with the containment barrier function, b) The BORA methodology is illustrated for a part of the release scenario “Release due to valve(s) in wrong position after maintenance” (called case example), c) Corrective action is performed when failures are revealed since only the detection is illustrated in the barrier block diagrams.

## **2. The BORA methodology**

The BORA approach for incorporation of human, operational and organizational factors in quantitative risk analysis is described in the following subsections. The BORA approach consists of the following steps:

- 1) Development of a basic risk model.
- 2) Assignment of industry average frequencies/probabilities of initiating events and basic events.
- 3) Identification of risk influencing factors (RIFs) and development of risk influence diagrams.
- 4) Assessment of the status of RIFs.
- 5) Calculation of industry average frequencies/probabilities of initiating events and basic events.
- 6) Calculation of installation specific risk, incorporating the effect of technical systems, technical conditions, human factors, operational conditions, and organizational factors.

### *2.1 Development of a basic risk model*

The basic building blocks of the BORA model are barrier block diagrams, event trees, fault trees, and influence diagrams. Barrier block diagrams are used to illustrate the event scenarios and the effect of barrier systems on the event sequences and consist of initiating events, barriers aimed to influence the event sequence in a desired direction, and possible outcomes of the event sequence. Event trees are used in the quantitative analysis of the scenarios. The performance of the safety barriers are analyzed by use of fault trees. These fault trees are linked to the event trees by use of the computer package Risk-Spectrum. Influence diagrams are used to analyze how the RIFs affect the initiating events in the event trees and the basic events in the fault trees.

Existing models from present QRAs have been taken as a starting point for the BORA models. However, the existing QRA models need to be extended and refined. Traditionally, the event modeling in QRAs has started with loss of containment as the initiating event, and the barriers aimed to limit the consequences of the release have been modeled. Causal analysis of hydrocarbon releases has normally not been included, since the assessment of hydrocarbon (HC) leaks has been related to generic frequency analysis. As mentioned earlier, this paper mainly deals with modeling of the containment function (or “prevent release of hydrocarbons”). However, in the overall BORA risk model, the accident scenarios are further developed, and the effect of the consequence reducing barriers are taken into account (Ref. 22).

Ref. 18 describes some 20 representative release scenarios that have been modeled by use of barrier block diagrams. Each barrier block diagram comprises the following:

- An initiating event, i.e. a deviation from the normal situation which may cause a release of hydrocarbons.
- Barrier systems aimed to prevent release of hydrocarbons.
- The possible outcomes of the event sequence, which depend upon the successful operation of the barrier system(s).
- The barrier block diagram for the release scenario “Release due to valve(s) in wrong position after maintenance” is illustrated in Fig. 1.

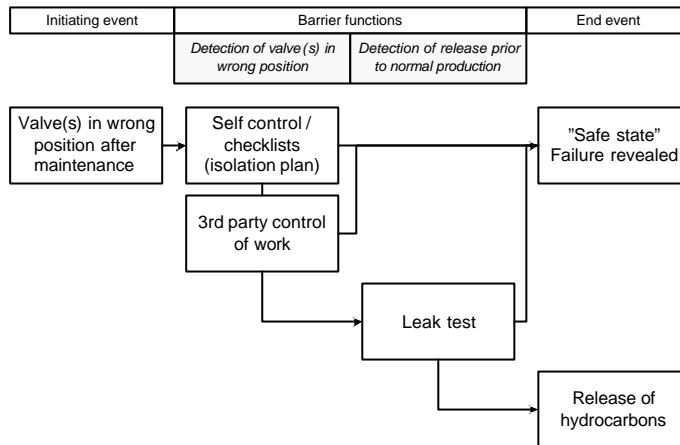


Fig. 1. Barrier block diagram for one release scenario.

As seen in Fig. 1, several of the barriers are non-physical by nature, thus requiring human and operational factors to be included in the risk model. For a complete description of each release scenario, see Ref. 18.

In order to perform a quantitative risk analysis, three main types of events need to be quantified:

- 1) The frequency of the initiating event, i.e. in the example case: “The frequency of valve in wrong position after maintenance”.
- 2) The probability of failure of the barrier systems, which for the example case includes: i) Failure to reveal valve(s) in wrong position after maintenance by self control/use of checklists, ii) Failure to reveal valve(s) in wrong position after maintenance by 3<sup>d</sup> party control of work, and iii) Failure to detect potential release during leak test prior to start-up.
- 3) The (end event) frequency of release of HC due to valve in wrong position (needed for further analysis of the effect of the consequence barriers).

The frequency of the initiating event is in our example a function of the annual number of maintenance operations where valve(s) may be set in wrong position in HC-systems, and the probability of setting a valve in wrong position per maintenance operation.

In order to determine the probability of failure of barrier systems, the barrier systems may be further analyzed by use of fault trees as shown in Fig. 2.

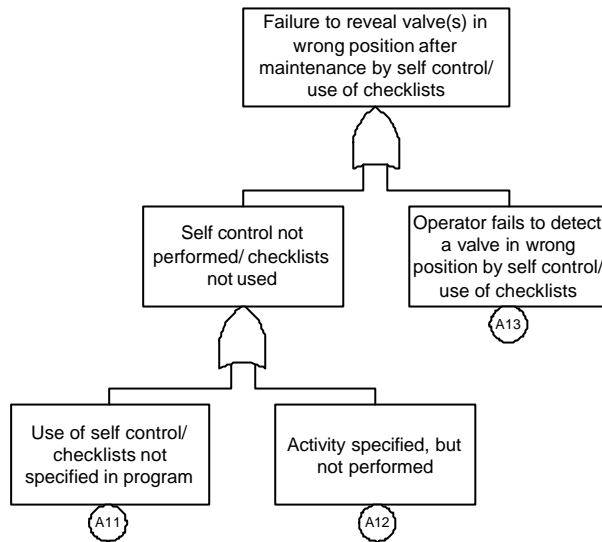


Fig. 2. Fault tree for failure of one barrier.

A similar analysis may be performed for all barriers for all the identified release scenarios. For further illustration of the quantification methodology in the BORA project, we consider the initiating event and the basic events shown in Fig. 1 and Fig. 2:

- Valve(s) in wrong position after maintenance that may cause release (the initiating event)
- Use of self control / checklists not specified in program (basic event A11)
- Use of self control / checklists specified, but not performed (basic event A12)
- The operator fails to detect valve(s) in wrong position by self control/use of checklists (basic event A13).

## 2.2 Assignment of average frequencies/probabilities

The first step in the quantification process is to assign industry average frequencies and probabilities for all the initiating events in the event trees and basic events in the fault trees.

Generic data may be found in generic databases or company internal databases. Alternatively, industry average values can be established by use of expert judgment. For our example case, Table 1 shows the assigned industry average frequencies and probabilities for the initiating events and basic events in Fig. 2.

Table 1. Assigned average frequencies and probabilities.

Event description	Assigned data
Annual frequency of valve(s) in wrong position after maintenance that may cause release	$F = 6$
Failure to specify self control / use of checklist	$P = 0.1$
Failure to perform self control/use of checklist	$P = 0.05$
Failure of operator to detect valve(s) in wrong position by self control/use of checklist	$P = 0.06$

The above figures are generic values, and ideally these average figures could be applied to calculate the frequency of release due to valve(s) in wrong position after maintenance. This calculated frequency will be calibrated against release statistics in order to obtain as credible figures as possible, i.e. figures that give good predictions of future quantities.

### 2.3 Qualitative risk influence modeling

The purpose of the RIF analysis is to assign platform specific failure probabilities for each initiating event and each barrier system, based on the status of the different risk influencing factors (RIFs) on the selected installation. Since the type and format of the initiating events and basic events to be assessed vary, they will be influenced by different types of RIFs.

Due to the complexity and variation in the types of events considered, a combined approach is preferred in order to develop RIFs; 1) a top-down approach where a generic list of RIFs are used as a basis, and 2) a bottom-up approach where the events to be assessed are chosen as a starting point.

The latter implies that specific RIFs are identified for each initiating or basic event based on the generic list of RIFs, and the generic list may be supplemented by new RIFs when necessary.

#### Framework for identification of RIFs

The proposed RIF framework is based on a review of several schemes of classification of MTO-factors:

- Classification of causes in methods for accident investigations like MTO-analysis (Ref. 3) and TRIPOD (Ref. 17).
- Classification of organizational factors in models for analysis of the influence of organizational factors on risk like I-RISK (Ref. 2) and the classification used in WPAM (Ref. 11).
- Classification of performing shaping factors (PSFs) in methods for human reliability analysis (HRA) like THERP (Ref. 19), CREAM (Ref. 9), and SLIM-MAUD (Ref. 6), and HRA databases like CORE-DATA (Ref. 8).

The selected framework is illustrated in Figure 3, and consists of the following groups of

RIFs:

- Personal characteristics (internal, psychological stressors, physiological stressors)
- Task characteristics
- Characteristics of the technical system
- Administrative control (procedures and disposable work descriptions)
- Organizational factors / operational philosophy.

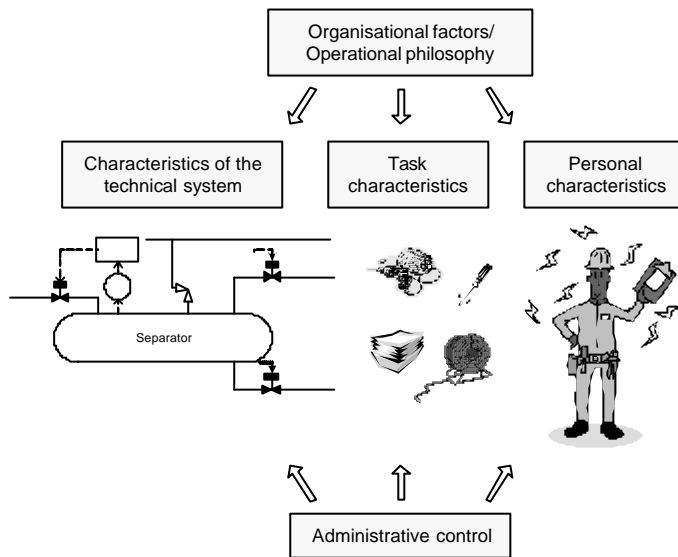


Fig. 3. Framework for identification of RIFs.

A preliminary taxonomy for RIFs within each group and short descriptions of each RIF are presented in Ref. 1, and Table 2 shows the specific RIFs within the main groups of RIFs.

#### RIFs - examples

RIFs for every initiating event in the event trees and every basic event in the fault trees should be identified. The number of RIFs for each event should be limited to maximum the six most important, preferably fewer. Input from operational personnel is important during this process in order to identify the most important RIFs.

Influence diagrams are used to illustrate and analyze the effect of risk influence factors on the initiating events and the basic events. An example on an influence diagram for the basic event “Operator fails to detect a valve in wrong position by self check/checklist” is shown in Fig. 4.

Table 2. RIFs within the different groups.

RIF group	Generic risk influence factors
Personal characteristics	Competence
	Working load / stress
	Fatigue
	Work environment
Task characteristics	Methodology
	Task complexity
	Time pressure
	Tools
	Spares
Characteristics of the technical system	Equipment design
	Material properties
	Process complexity
	HMI (labels, alarms, ergonomic factors)
	Maintainability/accessibility
	System feedback
Administrative control	Procedures
	Disposable work descriptions
Organizational factors / operational philosophy	Programs
	Work practice
	Supervision
	Communication
	Acceptance criteria
	Management of changes

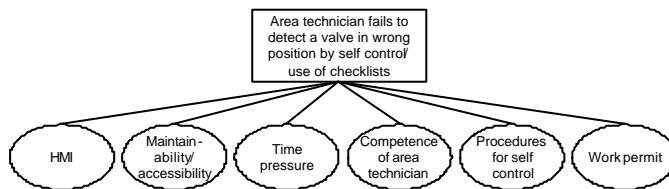


Fig. 4. Influence diagram for the basic event “Operator fails to detect a valve in wrong position by self check/checklist”.

Table 3 shows the RIFs for the rest of the basic events in our example case.



Table 3. Proposed RIFs for basic events in the example case.

Event description	RIFs
Valve in wrong position after maintenance	Process complexity Maintainability/accessibility HMI (valve labeling and position feedback features) Time pressure Competence (of area technician) Work permit
Self control/use of checklists not specified	Program for self control
Self control/use of checklists not performed	Work practice (regarding use of self control/checklists) Time pressure Work permit
Area technician fails to detect valves(s) in wrong position by self control/use of checklists	HMI (valve labeling and position feedback features) Maintainability/accessibility Time pressure Competence (of area technician) Procedures for self control Work permit

Similar influence diagrams are developed for each initiating event in the event trees and basic events in the fault trees.

So far, the qualitative basic risk model consisting of a set of barrier block diagrams/event trees, fault trees, and influence diagrams are developed. The next step is the quantification process.

#### 2.4 Scoring of RIFs

The first step is to assess the status of the RIFs. Two main options are proposed regarding scoring of RIFs:

- 1) Use of results from existing projects like TTS (Technical Condition Safety) (Ref. 20), the Risk Level on the Norwegian Continental Shelf (Ref. 16)), and MTO-investigations of incidents. The TTS project is a review method to map and monitor the technical safety level based on the status of safety critical elements and safety barriers, and each system are given scores (rating) according to predefined performance standards. Table 4 shows the definition of grades.
- 2) Expert judgment of status of RIFs on a specific platform. A scoring scheme for each RIF will be developed as basis for this assessment. An example on a scoring scheme is shown in Table 5.

Table 4. Definition of grades in the TTS project.

Rating	Description of safety level
A	Condition is significantly better than the reference level
B	Condition is in accordance with the reference level
C	Conditions satisfactory, but does not fully comply with the reference level
D	Condition is acceptable and within the statutory regulations' minimum intended safety level, but deviates significantly from the reference level
E	Condition with significant deficiencies as compared with "D"
F	Condition is unacceptable

Table 5. Example of scoring scale for the RIF procedures.

Score	Grade characteristics for the RIF procedures
A	Almost perfect procedures, with checklists, highlighting of important information, illustrations, etc.
B	Procedures better than industry average
C	Industry average procedures
D	Poorly written procedures and no highlighting
E	Procedures incomplete, out-of-date, inaccurate much cross-referencing, etc.
F	No procedures, even though the task demands them

These two approaches may be combined in practical assessments.

### 2.5 Calculation of installation specific frequencies/probabilities

The next task is to adjust the industry average probabilities based on the scoring of the RIFs. Three main aspects are discussed; a) the formulas for calculation of installation specific frequencies/ probabilities, b) assignment of appropriate values of Qs, and c) weighting of RIFs. The procedure is illustrated by use of numbers from the example case.

#### **Principles for adjustment**

The following principles for adjustment are proposed.

Let  $P_{rev}(A)$  be the "installation specific" probability of the failure event A. The probability  $P_{rev}(A)$  is determined by the following procedure;

$$P_{rev} = P_{ave} \sum_{i=1}^n w_i \cdot Q_i \quad (1)$$

where  $P_{ave}$  is the industry average probability,  $w_i$  is the weight / importance of RIF no.  $i$  for the event,  $Q_i$  is a measure of the status of RIF no.  $i$ , and  $n$  is the number of RIFs.

Here

$$\sum_{i=1}^n w_i = 1 \quad (2)$$

The challenge is now to determine appropriate values for  $Q_i$  and  $w_i$ .

### Determining appropriate values of $Q_i$

To determine the  $Q_i$ s we need to associate a number to each of the score A-F. This can be done in many ways, and the proposed scheme is :

- Determine by expert judgment  $P_{low}$  as the lower limit for  $P_{rev}$ .
- Determine by expert judgment  $P_{high}$  as the upper limit for  $P_{rev}$ .
- Then put for  $i = 1, 2, \dots, n$ ;

$$Q_i = \begin{cases} P_{low} / P_{ave} & \text{if } s_i = A \\ 1 & \text{if } s_i = C \\ P_{high} / P_{ave} & \text{if } s_i = F \end{cases} \quad (3)$$

where  $s_i$  denotes the score or status of RIF no  $i$ . Hence if the score  $s_i$  is A, and  $P_{low}$  is 10 % of  $P_{ave}$ , then  $Q_i$  is equal to 0.1. And if the score  $s_i$  is F, and  $P_{high}$  is ten times higher than  $P_{ave}$ , then  $Q_i$  is equal to 10. If the score  $s_i$  is C, then  $Q_i$  is equal to 1.

Furthermore, if all scores are C, then  $P_{rev} = P_{ave}$ , if all scores are A, then  $P_{rev} = P_{low}$ , and if all scores are F, then  $P_{rev} = P_{high}$ .

So far, as a first approximation we have found it appropriate for practical analysis to use a fixed factor of ten to describe the variations caused by different scores, from A to F. That is, if all scores are A,  $P_{low}$  is 10 % of  $P_{ave}$ , and if all the scores  $s_i$  are F, then  $P_{high}$  is ten times higher than  $P_{ave}$ .

Furthermore; we have adopted the grade score from the TTS project; A=3, B=2, C=1, D=0, E=-2 and F=-5. Thus we have, letting  $Q_i(j)$  denote the value of  $Q_i$  if the score  $s_i$  takes the value  $j$ ;

Table 6. Adaptation of scores from the TTS project.

Score $s_i = j$	3 (A)	2 (B)	1 (C)	0 (D)	-2 (E)	-5 (F)
$Q_i(j)$	0,10		1			10

Hence it remains to determine  $Q_i(j)$  for  $j=2, 0$ , and  $-2$ . Using a linear transform seems natural, and we obtain the following  $Q$  values;

For  $j=0$  and  $-2$  (E and D):

$$Q_i(j) = Q_i(-5) + (j - 1)(Q_i(1) - Q_i(-5)) / (1 - (-5))$$

And for  $j=2$  (B):

$$Q_i(j) = Q_i(1) + (j - 1) (Q_i(3) - Q_i(1)) / (3-1),$$

which gives the appropriate values for  $Q_i$  as shown in Table 7.

Table 7. Appropriate values for  $Q_i$ s.

Score $s_i = j$	3 (A)	2 (B)	1 (C)	0 (D)	-2 (E)	-5 (F)
$Q_i(j)$	0,10	0,55	1	2,5	5,5	10

### Weighting of RIFs

To determine the weights  $w_i$ s, we start from a weight  $w_i$  equal to 10 assigned to the most important RIF (RIF no. i). The other RIFs are afterwards given relative weights (10 – 8 – 6 – 4 – 2). The idea is to think of relative changes in the probability given that the score of RIF no. i is changed from A to F. According to (2), normalization is required to ensure that the sums of the  $w_i$ s are equal to 1.

### Calculation example

An example on results from calculation of  $P_{rev}$  when  $P_{ave} = 0.01$ ,  $P_{high} = 0.1$ , and  $P_{low} = 0.001$  is shown in Table 8.

Table 8. Example - Calculation of  $P_{rev}$ .

RIF no. i	Weight of RIF i ( $w_i$ )	Normalized weight	Status of RIF i ( $s_i$ )	$Q_i$	$w_i * Q_i$
1	4	0.12	B	0.55	0.065
2	6	0.18	C	1	0.176
3	4	0.12	E	5.5	0.647
4	6	0.18	D	2.5	0.441
5	10	0.29	C	1	0.294
6	4	0.12	D	2.5	0.294
Sum	34	1.0	-	-	1.918

By use of (1),  $P_{rev}$  is equal to ( $P_{ave} * 1.918$ ). In our example case, the RIF analysis gave an increase of the probability of occurrence of the basic event by a factor 1.9 (from  $P_{ave} = 0.01$  to  $P_{rev} = 0.019$ ).

### 2.6 Recalculation of the installation specific risk

A revised value for the installation specific risk may be calculated by use of the platform specific data ( $P_{rev}$ ) as input data in the risk model (event trees/fault trees) described in Section 2.1. The revised risk value takes the technical systems on the platform, the technical conditions, human factors, operational conditions, and organizational factors into consideration.

### **3. Discussion**

The following subsections contain a discussion of each step of the BORA methodology as described in Section 2.

#### *3.1 Basic risk model in the BORA methodology*

The basic risk model may be seen as an extended QRA-model, however, there are several extensions compared to status quo regarding offshore QRA's:

- Event trees and fault trees are linked in one common risk model.
- Detailed modeling of the loss of containment barrier, including initiating events reflecting different causes of HC release and safety barriers aimed to prevent release of HC.
- Incorporation of operational activities functioning as operational barriers such as use of checklists, 3<sup>d</sup> party control of work, and manual inspection in order to detect corrosion in the risk model.

The calculated release frequencies from the different release scenarios constitute the input to the analyses of the consequences. The BORA methodology may use release statistics in order to calibrate the quantitative numbers obtained by analysis of the release scenarios. Also other ways to calibrate the numbers will be considered.

However, it is the possibility to evaluate the relative importance of the different release preventive barriers and the effect of changes that is important regarding control of risk and prioritization of risk reducing measures.

#### *3.2 Assignment of industry average frequencies/ probabilities*

Assignment of industry average frequencies/ probabilities implies use of existing approaches and data from generic databases in addition to extraction of platform specific information regarding operational conditions and experience from surveillance of operational activities. Data recovery from such systems may require extensive manual work and some interpretations of the recorded data may be necessary.

Due to the novelty of the modeling of the containment barrier, it may be difficult to find relevant data. One critical aspect is the availability of relevant human reliability data, and some expert judgment may be necessary in order to assign the probabilities.

When it comes to the consequence barrier systems, there are actually quite considerable amounts of data available for selected barrier elements, both on the industry average level, and the installation specific level as basis for the quantification.

#### *3.3 Risk influence diagrams*

The purpose of the qualitative risk influence modeling is to identify the most important factors influencing each analyzed initiating event and basic event. In order to keep the

operational risk analysis in a manageable size, it is necessary to limit the number of RIFs for each event. So far, we allow maximum 6 RIFs (the most important ones) for each event.

The involvement of operational personnel knowing the platform and the operational activities is an important aspect during identification of RIFs.

The framework for identification of RIFs shown in Fig. 3 should be considered as a draft framework based on a review of literature concerning risk influencing factors. During testing (case studies) of the BORA methodology, this framework may be modified due to experience and comments from the operational personnel.

### *3.4 Assessment of status of RIFs*

It has been an objective to use existing information to score the RIFs, and as far as possible results from the TTS project should be used. But the TTS is focusing on technical systems and is only relevant for some RIFs, primarily the technical ones, and focus is on consequence reducing barriers. However, the TTS project also covers other RIFs to some extent. TTS studies are not executed for all platforms on the Norwegian Continental Shelf, therefore there is need for alternative methods for assessment of the status of the RIFs.

The 6-point score scale has been adopted from the TTS project. One challenge during further work is to develop adequate scoring tables for all the RIFs. These scoring tables should be general, but suitable for assessment of the status of specific RIFs. The status assessment should be based on input from operational personnel on the platform.

One important aspect to consider is how specific the assessment of status of each RIF should be in order to obtain credible results. For example, is it possible to give a general score for the RIF "procedure" that is credible for all procedures on the platform, or is it necessary to assess explicit specific procedures related to specific scenarios. As far as possible, the level of detail should be sufficiently detailed and specific to reflect scenario specific factors, but in practice, it may be necessary to be somewhat more general.

It has been discussed to use the results from a RNNS questionnaire (Ref. 16) and MTO accident investigations in order to score the RIFs. Most probably data from the RNNS questionnaire could have been used for scoring of the RIFs at a general level, but they are not as suitable for scoring of scenario specific RIFs. An underlying problem with use of the MTO investigations is that the events considered only include situations where the status of the identified RIFs has contributed to an incident or an accident, so the status of the RIFs in general is not assessed. Ideally, more explicit basis for scoring of RIFs should be used, but the wish to use existing data will always exist in practice.

Scoring of RIFs based on results from the RNNS questionnaire will be tested out in at least one case study.

### *3.5 Calculation of installation specific frequencies/ probabilities*

The two fundamental issues regarding calculation of installation specific frequencies/probabilities are; a) transformation of scoring to quantitative status, and b) assessment of quantitative weights (importance).

Regarding the transformation of scoring to a quantitative status, the principles are

similar to the I-RISK project. Some assumptions, like the use of a fixed factor of 10 to describe the variations caused by different status of the RIFs and the use of the grade score from the TTS project ( $A = 3 - F = -5$ ), may be subject for discussion. As regards the former assumption, it may be argued that this will reduce the possibility to emphasize the differences between different factors as they may vary considerably, and a factor of 10 may be too high in some cases. As regards the latter assumption, the scale implies that a good character (A) will not compensate for a poor (F) even if the step in score is the same. Nevertheless, by use of these assumptions, the calculated scores in Table 6 seem all reasonable, thus this procedure is recommended used as a first approximation in the BORA methodology. However, these assumptions will be discussed in the further work.

Regarding the weighting process, the proposed approach is a simple approach that is easy to perform in practice. However, other methods like paired comparison will also be considered used in the case studies.

### *3.6 Recalculation of the risk*

Use of the revised frequencies/probabilities for initiating events and basic events as input to the basic risk model give a risk number taking installation specific factors such as technical systems, the technical conditions, human factors, operational conditions, and organizational factors into consideration.

Compared to a traditional QRA model, the BORA model is a more detailed model, and includes considerable more risk influencing factors that gives more detailed information of factors contributing to the total risk, i.e. a more detailed risk picture. The analysis allows us to study the effect of human and organizational factors on risk, and thus provide decision support. The risk analysis can be used to identify critical factors, as well as expressing the effect of risk reducing measures.

## **4. Conclusions and further work**

This paper provides a basis for further work on how operational risk analysis reflecting installation specific factors as technical systems, technical conditions, human factors, operational conditions, and organizational factors as far as reasonably practicable should be carried out in the offshore industry. Central elements in the proposed BORA methodology are use of barrier block diagrams, event trees, fault trees, and influence diagrams.

One important aspect to consider regarding operational risk analysis is how specific the assessment of different operational aspects and RIFs should be in order to obtain credible results. It is necessary that the resolution in the analysis is concurrent with the objectives of the analysis, i.e. that the factors considered in the analysis are at least as detailed as the factors that are addressed in the decision-making. Since the BORA-model is more detailed and includes considerable more risk influencing factors (technical, human, operational, and organizational factors) compared to standard QRA's, it constitutes a step forward regarding use of risk-informed decision-making in the offshore industry.

Further work is carried out in order to test the proposed methodology on oil producing platforms in the North Sea, and some of the aspects discussed in Section 3 will be further

addressed as a part of these case studies. There are also other aspects that are not considered in this paper that will be addressed in the case studies. An example is analysis of dependencies, for example between different risk influencing factors in the model. A simple approach is proposed in Ref. 1 for dealing with interaction effects among RIFs. The use of independence when assigning probabilities in for example the fault trees is also covered in Ref. 1. It is argued that the RIFs to some extent justifies the use of independence, as the probabilities are conditioned on the RIFs.

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