Incorporating human and organizational factors in risk analysis for offshore installations

S. Sklet
NTNU/SINTEF, Trondheim, Norway

T. Aven
UiS, Stavanger, Norway

S. Hauge
SINTEF, Trondheim, Norway

J.E. Vinnem
Preventor/UiS, Stavanger, Norway

ABSTRACT: This paper presents a methodology for quantitative risk analysis on oil and gas production platforms 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 intention of the analysis is to reflect installation specific factors both with respect to technical systems, operational conditions as well as human and organizational factors.

1 INTRODUCTION

1.1 *Background*

The Petroleum Safety Authority Norway (PSA) is focusing on safety barriers and their performance in the present regulations concerning health, safety and environment (PSA, 2001). Traditionally, offshore quantitative risk analyses (QRAs) have had a rather crude analysis of barrier performance, emphasizing technical aspects related to consequence reducing systems. One of the conclusions in Vinnem et al (2003) was that a more detailed analysis of safety barriers is required. Based on this, the research activity "BORA" (Barrier- and Operational Risk Analysis) was initiated.

The aim of the BORA project (Vinnem et al 2004) 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 (Pitblado, 1990), MACHINE (Embrey, 1992), WPAM (Davioudian et al, 1994a & b), SAM (Paté-Cornell & Murphy, 1996), I-RISK (Bellamy et al, 1999), and ARAMIS (Hourtolou & Salvi, 2004). 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.

1.2 *Purpose and structure of the paper*

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

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.

1.3 *Delimitations and assumptions*

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 RiskSpectrum. 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 QRA’s 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 (Vinnem et al, 2004).

Sklet & Hauge (2004) 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 Figure 1.

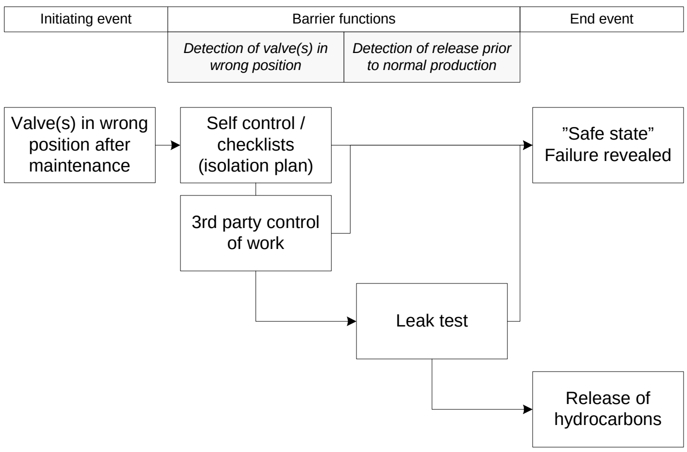

Figure 1. Barrier block diagram for one release scenario.

As seen in Figure 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, reference is made to Sklet & Hauge (2004).

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 3rd party control of work, and iii) Fail-

ure 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 Figure 2.

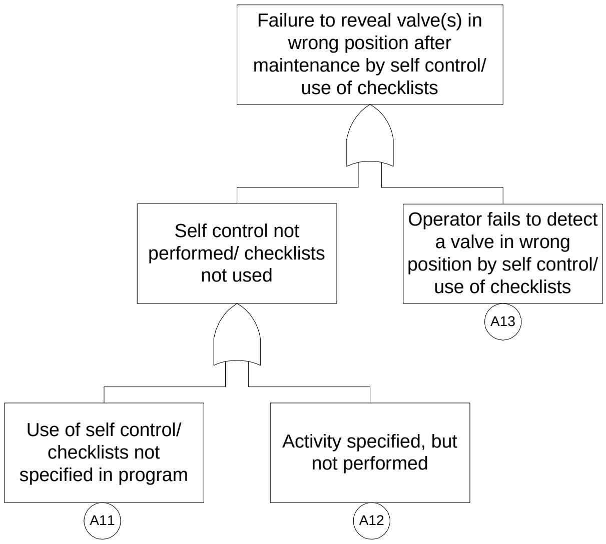

Figure 2. Fault tree for failure of one barrier.

Corresponding 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 Figure 1 and Figure 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 Figure 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.

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.

2.3.1 *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 (Bento, 2001) and TRIPOD (Reason, 1997).
- Classification of organizational factors in models for analysis of the influence of organizational factors on risk like I-RISK (Bellamy et al, 1999) and the classification used in WPAM (Jacobs & Haber, 1994).
- Classification of performing shaping factors (PSFs) in methods for human reliability analysis (HRA) like THERP (Swain & Guttmann, 1983), CREAM (Hollnagel, 1998), and SLIM-MAUD (Embrey et al, 1984), and HRA databases like CORE-DATA (Gibson et al, 1998).

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.

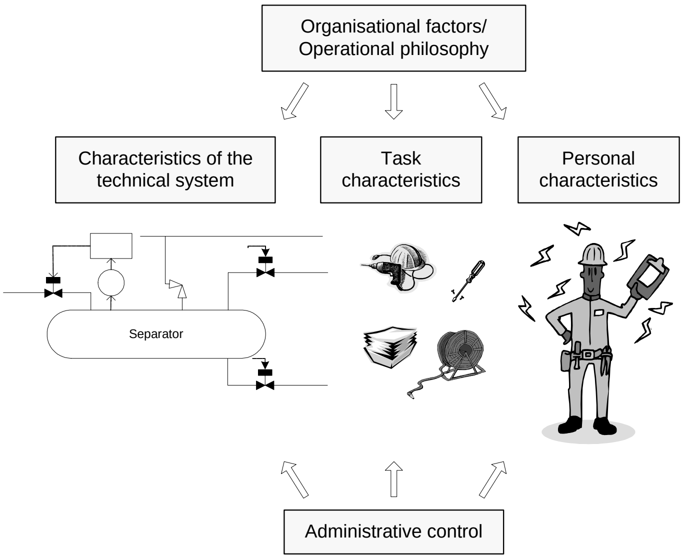

Figure 3. Framework for identification of RIFs.

A preliminary taxonomy for RIFs within each group and short descriptions of each RIF are presented in Aven et al (2004), and Table 2 shows the specific RIFs within the main groups of RIFs.

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 Technical condition
Administrative control	Procedures Disposable work descriptions
Organizational factors / operational philosophy	Programs Work practice Supervision Communication Acceptance criteria Management of changes

2.3.2 *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 Figure 4.

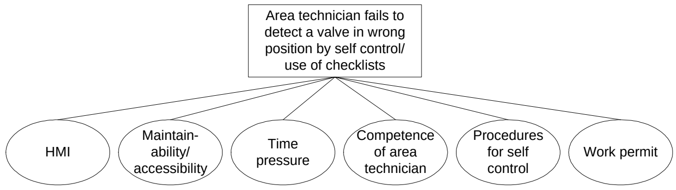

Figure 4. Influence diagram for the basic event "Operator fails to detect a valve in wrong position by self check/checklist".

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

Corresponding influence diagrams should be 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 Technical Condition Safety (TTS)[1] (Thomassen & Sørum, 2002), the Risk Level on the Norwegian Continental Shelf (PSA, 2004), 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.

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

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 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 Q_is, and c) weighting of RIFs. The procedure is illustrated by use of numbers from the example case.

2.5.1 *Principles for adjustment*

The following principles for adjustment are proposed.

[1] Statoil's project is called TTS. Hydro has a similar project, referred to as the TST project.

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;

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

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

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

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

2.5.2 *Determining appropriate values of Q_i*

To determine the Q_is 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,…n;

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

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_is.

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

2.5.3 *Weighting of RIFs*

To determine the weights w_is, 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.

2.5.4 *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 subsection 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, 3rd 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 on 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 Figure 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 (PSA, 2004) 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. Even though there is uncertainty in the risk numbers, the BORA model may be used to estimate the importance of safety barriers and the effect of changes during operations.

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 during the autumn 2004 and winter 2005 in order to test the proposed methodology on an oil producing platform in the North Sea, and some of the aspects discussed in section 3 will be further addressed as a part of this case study. There are also other aspects that are not considered in this paper that will be addressed in the case study. An example is analysis of dependence between different risk influencing factors in the model.

5 ACKNOWLEDGEMENT

The BORA project is financed by the Research Council of Norway (NFR), Health and Safety Executive in the United Kingdom (HSE), and The Norwegian Oil Industry Association (OLF), whose contributions are gratefully acknowledged.

6 REFERENCES

Aven T, Hauge S, Sklet S & Vinnem JE, 2004. *Operational Risk Analysis – Total Analysis of Physical and Non-physical Barriers*, Draft 0 rev. 1, 3. July 2004, Report No. 200254-04, Preventor, Stavanger, Norway.

Bellamy LJ, Papazoglou IA, Hale AR, Aneziris ON, Ale BJM, Morris MI, Oh JIH. *I-RISK Development of an Integrated Technical and Management Risk Control and Monitoring Methodology for Managing and Quantifying On-Site and Off-Site Risks*. Main Report, September 1999. Contract No. ENVA-CT96-0243

Bento, J-P, 2001. *Menneske – Teknologi – Organisasjon Veiledning for gjennomføring av MTO-analyser*. Kurskompendium for Oljedirektoratet, Oversatt av Statoil, November 2001

Davoudian K., Wu J-S. & Apostolakis G. 1994a. Incorporating organisational factors into risk assessment through the analysis of work processes. *Reliability Engineering and System Safety*, 1994, 45, 85-105.

Davoudian, K. Wu J-S & Apostolakis G. 1994b. The work process analysis model (WPAM-II) *Reliability Engineering and System Safety*, 1994, 45, 107-125.

Embrey D.E. 1992. Incorporating management and organisational factors into probabilistic safety assessment. *Reliability Engineering & System Safety*, 1992, Vol. 38, no. 1-2, 199-208.

Embrey D.E., Humphreys P., Rosa E.A., Kirwan B., & Rea K. 1984. *SLIM-MAUD: An approach to assessing human error probabilities using structured expert judgment*, NUREG/CR-3518, Department of Energy, USA, 1984

Gibson H., Basra G. & Kirwan B. 1998. *Development of the CORE-DATA database*, Paper dated 23.04.98, University of Birmingham, UK

Hollnagel, E. 1998. *Cognitive Reliability and Error Analysis Method (CREAM)*. ISB 0-08-0428487, Elsevier, UK.

Hourtolou, D. and Salvi, O., ARAMIS Project: development of an integrated accidental risk assessment methodology for industries in the framework of SEVESO II directive, In Bedford, T. and Gelder, P. H. A. J. M. van (eds), *Safety & Reliability - ESREL 2003*, pp. 829-836, 2003

Jacobs R. & Haber S., 1994. Organizational processes and nuclear power plant safety. Reliability Engineering and System Safety, 45 (1994) 75-83.

Øien K. & Sklet S., 2001. *Metodikk for utarbeidelse av organisatoriske risikoindikatorer*. (in Norwegian). SINTEF report STF38 A00422, Trondheim, Norway

Papazoglou IA, Bellamy LJ, Hale AR, Aneziris ON, Post JG, Oh JIH. 2003. I-Risk: development of an integrated technical and Management risk methodology for chemical installations. *Journal of Loss Prevention in the process industries*, 16 (2003) 575 – 591, Elsevier

Paté-Cornell E.M. & Murphy D.M. 1996. Human and management factors in probabilistic risk analysis: the SAM approach and observations from recent applications. *Reliability Engineering and System Safety*, 53 (1996) 115-126, Elsevier Science

Pitblado R.M., Williams J.C. & Slater D.H. 1990. Quantitative Assessment of Process Safety Programs. *Plant/Operations Progress*, Vol. 9, No. 3, 1990.

PSA, 2001. *Regulations relating to management in the petroleum activities (The Management Regulation)*, The Petroleum Safety Authority Norway, Stavanger, Norway.

PSA, 2004. *Trends in Risk Levels on the Norwegian Continental Shelf Main report Phase 4 – 2003* (in Norwegian). The Petroleum Safety Authority Norway, Stavanger, Norway.

Reason J, 1997. *Managing the Risks of Organizational Accidents*, ISBN 1 84014 105 0. Ashgate.

Sklet, S. & Hauge S. 2004. *Safety barriers to prevent release of hydrocarbons during production of oil and gas*. SINTEF report STF38 A04419, Trondheim, Norway.

Swain, A.D. & Guttmann, H.E. 1983. *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*, Final Report, NUREG/CR-1278, SAND80-0200, US NRC, 1983.

Thomassen, O., Sørum, M. 2002. Mapping and monitoring the safety level. *SPE 73923*, Society of Petroleum Engineers.

Vinnem JE, Aven T, Hundseid H, Vassmyr KA, Vollen F & Øien K, 2003. Risk assessments for offshore installations in the operational phase, In Bedford, T. and Gelder, P. H. A. J. M. van (eds) Safety & Reliability -ESREL 2003.

Vinnem, JE, Aven T, Hauge S, Seljelid, J & Veire G, 2004. Integrated Barrier Analysis in Operational Risk Assessment in Offshore Petroleum Operations. In Spitzer, Schmocker & Dang (eds) *Probabilistic Safety Assessment and Management, PSAM7 – ESREL'04*, Springer.