Risk, Reliability and Societal Safety – Aven & Vinnem (eds)
© 2007 Taylor & Francis Group, London, ISBN 978-0-415-44786-7

Generalised methodology for operational risk analysis

Jan Erik Vinnem
Preventor/University of Stavanger, Stavanger, Norway

Jorunn Seljelid & Stein Haugen
Safetec Nordic, Trondheim, Norway

Snorre Sklet
SINTEF Technology and Society, Trondheim, Norway

Terje Aven
University of Stavanger, Stavanger, Norway

ABSTRACT: The BORA project has developed a model based on the use of Event Trees, Fault Trees, Influence Diagrams, Risk Influencing Factors (RIFs) and simplified modelling of dependencies between RIFs. The model has been outlined in several earlier papers. Some case studies have been performed in the project. The experience from these case studies has been used in order to develop a generalised methodology for analysis of operational barriers that are intended to prevent hydrocarbon leaks. A stepwise description of this generalised methodology is presented and discussed in the paper.

1 INTRODUCTION

The offshore petroleum industry has for a long time invested considerable resources in engineering defences, or barriers, against fire and explosion hazards on the installations. The performance of barriers is to some extent followed up through performance standards and Key Performance Indicators, though often not extensively. Safety systems are usually addressed on a one-by-one basis, not allowing dependencies and common mode/cause failures to be identified.

Half of the leaks from hydrocarbon containing equipment occur in connection with manual activities in hazardous areas, during which engineered defences often are partially inhibited or passivated, in order not to cause disruption of stable production. The occurrence of these leaks is a clear indication that operational barriers relating to containment of leaks are not functioning sufficiently well during these operations. There is an obvious need to understand better the performance of barriers, particularly non-technical, during execution of manual activities.

Several R&D projects are being conducted in the Norwegian offshore petroleum industry addressing performance of defences/barriers. Most of these are internal projects, but a few are openly available, see Sandøy et al. (2001), Thomassen and Sørum (2002) and Vinnem et al. (2004b). Most of these studies have a limited scope with respect to the barriers covered, and few of these are aimed at quantification of barrier performance. Health and Safety Executive in the UK are also considering a similar approach focusing on barriers/defences (Miles 2004).

QRA (Quantified Risk Assessment) studies for the offshore petroleum industry have traditionally had a rather narrow analysis of barrier performance. The nuclear industry has on the other hand used extensive studies of barrier performance, with objectives that match quite well the objectives for the present work. A pilot study was therefore conducted, funded by the Norwegian Petroleum Directorate, in order to illustrate the application of analytical approaches and tools from the nuclear field. This included a relatively limited pilot study of selected barriers on an example installation (Bäckström 2003). Other projects that have provided useful input are:

- Several projects addressing non-physical (i.e. human and organisational) barriers
- MTO-structured accident and incident investigations (i.e. with equal focus on human, organisational and technical causation)
- Working group in ‘working together for safety’ project addressing terminology for physical and non-physical barriers (SfS 2004)
- Cause analysis for process leaks (Nilsen et al. 2000)

In a paper presented at ESREL 2003 (Vinnem et al. 2003a), operational risk assessments were discussed. It was concluded that there is a clear need for improvement of the analysis of barriers. These aspects form the outset for an extensive research activity called the BORA (Barrier and Operational Risk Analysis) project (Vinnem et al. 2003b). A PSAM7 paper (Vinnem 2004a) gave some preliminary observations and introduced a proposed approach.

The BORA project has been carried out in the period 2003 through 2006, and was concluded in 2006 with a generalised methodology, based on the initial methodology formulation as well as the experience from the case studies. This paper presents the generalised methodology, which is not presented in any previous papers.

2 OBJECTIVES

A case study with complete modelling and analysis of barriers on offshore production installations has been carried out, for physical and non-physical barriers. Barriers intended to prevent the incident occurring along with those intended to eliminate/reduce consequences are included, and particular emphasis is placed on barriers during execution of operational activities. The results from the study should enable both industry and authorities to improve safety through:

- Knowledge about overall performance of barriers and improvement potentials
- Identification of the need to reinforce the total set of barriers, especially during operational activities
- Identification of efficient risk reduction measures for barriers, as well as effective modifications and configuration changes.

The analysis has been intended as a quantitative analysis as far as is possible. The performance of barriers is in general characterised by reliability/availability, functionality and robustness, according to regulatory requirements. All of these performance measures are addressed. The Norwegian regulations require that dependencies between barriers shall be known. The analysis is therefore performed such that, where relevant, common cause or mode failures and dependencies between barrier elements are accounted for.

One of the main aspects of the project is to address the barrier situation in detail when operational activities are carried out. A list of ten suitably defined activities and conditions that are associated with hydrocarbon leak risk was established during the work with activity indicators (Vinnem et al. 2004b), which is also used in the BORA project.

3 OVERALL METHODOLOGY

3.1 *Main steps of the methodology*

The overall methodology that has been developed is based on the work undertaken in the BORA project. The main basis can be summarized as follows:

- A literature review was undertaken to identify potential approaches and ideas for use in the development of a methodology for this project.
- A proposed methodology was developed.
- The proposed methodology was tested in several case studies.

From this, a theoretical basis has been established and experience from use has been gained. A methodology for establishing general models for describing the risk in operations has been developed.

The overall elements of a generic risk model are illustrated in Figure 1. The figure also shows the different types of input data, which are discussed in the following subsections.

It should be noted that the term 'initiating event' usually is interpreted as hydrocarbon leaks in standard QRA analysis. In the BORA methodology, initiating events are interpreted as deviations from normal conditions, either operationally or technically. If the barrier (sub)functions intended to prevent these deviations to result in loss of containment all fail, then an uncontrolled release of hydrocarbons may occur. The elements can be briefly described as follows:

- The starting point for the model is a set of work operations and equipment types in hydrocarbon systems. Current QRAs will in most cases model the quantity of equipment in detail, but will not take into account platform specific characteristics of the equipment or work operations. An example

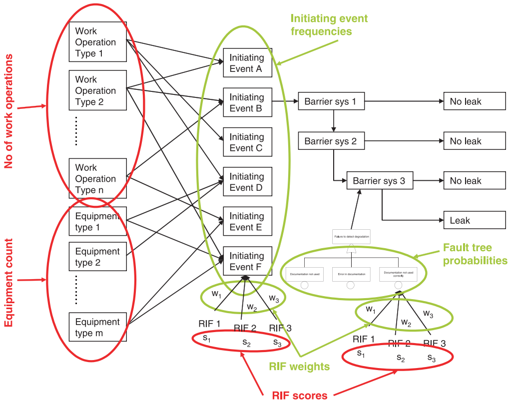

Figure 1. Illustration of a generic risk model, generic information vs installation specific information used in study.

of a work operation is "work on depressurized hydrocarbon containing equipment".

- Various types of errors or failures during the work operations may lead to a leak. These are termed "Initiating Events". One example is replacement of a flange gasket where the gasket may be inserted wrongly or bolts may not be tightened correctly. Likewise, the equipment itself may fail due to technical causes, such as corrosion, fatigue, erosion or other degradation mechanisms. For each work operation, there is a certain probability that different types of Initiating Events will occur. The probability of this happening will be influenced by a set of "Risk Influencing Factors" (RIFs). As an example, the probability of making an error when replacing a flange gasket may be dependent on the competence of the mechanic doing the work and the time pressure when the work is being performed. If the competence is high, the probability of failure will be low while if the work situation is stressful the failure probability may increase. The importance of the RIF (how strongly the RIF influences the probability) is described by a weight (w). Further, the condition of the RIF for the specific installation being considered is described by a score (s).
- In most cases, there will be one or more barriers implemented to prevent an Initiating Event from causing a leak. These barriers are modeled using Barrier Block Diagrams (BBD, similar to event trees). The probability of a barrier failing is usually modeled using Fault Tree Analysis (FTA). For each of the basic events in the fault tree, RIFs are also identified.

In the following, the individual steps in the model are described in some more detail. More details are also provided in Aven et al. (2006) and Haugen et al. (2007).

3.2 *Work operations and equipment units*

The first step in the development of the model has been to define work operations and equipment units that may cause a leak. In order to have a manageable risk model, a limited number of generic work operations are defined, covering operations which may directly cause a leak or introduce errors/weaknesses/failures in the system which may cause a leak at a later point in time. The work operations are defined in such a way that they will have as many common characteristics as possible such that the RIFs influencing the probability of making errors will be the same or very similar for all specific operations grouped together.

Further, generic equipment units or equipment packages are also defined. This could be e.g. "compressor package". For each of these generic equipment packages, the number of flanges, valves, instrument connections etc is specified.

Based on this, an "average" platform with average leak frequencies can be established. Also a simplified approach is proposed, using generic leak frequency data and adjusting these to take into account variations in number of work operations for a specific installation.

In order to establish a suitable set of typical work operations, the starting point is to consider the types of equipment located in the process areas and what operations are being performed on this equipment. Principally, the equipment can be divided in two groups:

- Hydrocarbon containing systems/equipment
- Other equipment and structures. This will include all sorts of equipment in the process areas such as utility equipment, safety systems, electrical equipment, structures etc.

There will be a principal difference between work operations performed on these two groups of equipment since work on the second group of equipment only indirectly can lead to a leak of hydrocarbons, e.g. due to dropped or swinging objects (external impacts). However, when performing work on the hydrocarbon containing equipment, the operation can directly lead to a release, e.g. if a wrong valve is opened.

Further, when considering hydrocarbon containing equipment, it is natural to do a further subdivision:

- Pressurized equipment
- Isolated, depressurized equipment

The errors or failures required for a release to occur in these situations will be different and are therefore natural to consider separately. We thus end up with splitting on three situations:

- Work on pressurized, hydrocarbon containing equipment
- Work on isolated and depressurized, hydrocarbon containing equipment
- Work on other equipment and structures

Data about the number of work operations are not readily available. However, some information is available form earlier work that has been performed (Torjussen 2003) and a summary of this is presented in the following.

First of all, the previous section showed a breakdown of operations into a total of 7 types of operations. It has been found that more than 95% of the leaks occur in relation to three types of operations:

- Work on pressurized equipment – Normal operation
- Work on depressurized equipment – Small units
- Work on depressurized equipment – Major units

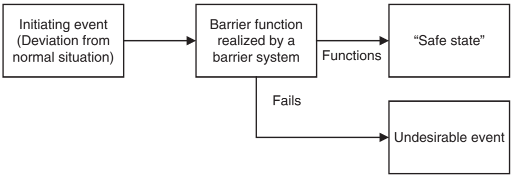

Figure 2. Illustration of a barrier block diagram

It is therefore particularly important to have data related to these operations, while the others contribute much less and therefore are less important to cover.

Torjussen (2003) has gathered information about work tasks for one specific large, integrated production platform. Work orders for one year have been studied and the number of operations of a predefined set of categories has been determined.

The number of work operations and equipment units are among the input data in Figure 1.

3.3 *Initiating events*

The errors or failures that may develop into a leak are termed Initiating Events (IE). The IEs are based on review of investigation reports from actual leaks that have occurred on the Norwegian Continental Shelf. The causes of the leaks have been identified and structured. Further, the IEs have been grouped according to how they are mitigated against, i.e. what barriers are in place to prevent an IE from developing into a leak. Six groups of IEs have been defined:

A. Technical degradation of system
B. Human intervention introducing latent error
C. Human intervention causing immediate release
D. Process disturbance
E. Inherent design errors
F. External impact

The event sequence following on from the initiating event is visualized in a *barrier block diagram* as illustrated in Figure 2. A barrier block diagram consists of an initiating event, arrows that show the event sequence, barrier functions realized by barrier systems, and possible outcomes. A horizontal arrow indicates that a barrier system functions (i.e., fulfils its function), whereas an arrow pointing downwards indicates failure to fulfil the barrier function. In our case, the undesirable event is release of hydrocarbons (loss of containment).

The list of initiating events has been somewhat generalized and restructured since its first formulation. The final list is presented in Table 1.

Detailed analysis of causes and circumstances of hydrocarbon leaks in the Norwegian sector in the period 2001–2005 was used as input to the work. Some of these results are presented in Vinnem et al (2007).

Table 1. Overview of initiating event types and subtypes.

Initiating Event Type	Initiating Events
A. Technical degradation of system	1. Degradation of valve sealing 2. Degradation of flange gasket 3. Loss of bolt tensioning 4. Fatigue 5. Internal corrosion 6. External corrosion 7. Erosion 8. Other causes
B. Human intervention introduction latent error	1. Incorrect blinding/isolation 2. Incorrect fitting of flanges or bolts during maintenance 3. Valve(s) in incorrect position after maintenance 4. Erroneous choice or installations of sealing device 5. Maloperation of valve(s) during manual operation* 6. Maloperation of temporary hoses.
C. Human intervention causing immediate release	1. Break-down of isolation system during maintenance. 2. Maloperation of valve(s) during manual operation* 3. Work on wrong equipment, not known to be pressurised
D. Process disturbance	1. Overpressure 2. Overflow/overfilling
E. Inherent design errors	Design related failures
F. External events	1. Impact from falling object 2. Impact from bumping/collision

* May lead to either introduction of latent error or immediate release.

Some further results are presented in Figure 3 and Figure 4.

3.4 *Performance of barrier systems*

The performance of barrier systems is modelled using fault trees. In order to generalize the fault trees, the main structure which is described in the following, is applied where possible.

The top events in the fault trees are generally expressed as "Failure or degradation of barrier system". More specifically, this can be related to failure to detect degradation of a system, failure to detect an error introduced in the system etc.

The causes of the top events are generally grouped into three groups of events:

- Inadequate or insufficient "functionality" of the barrier system. This could be simply that the barrier

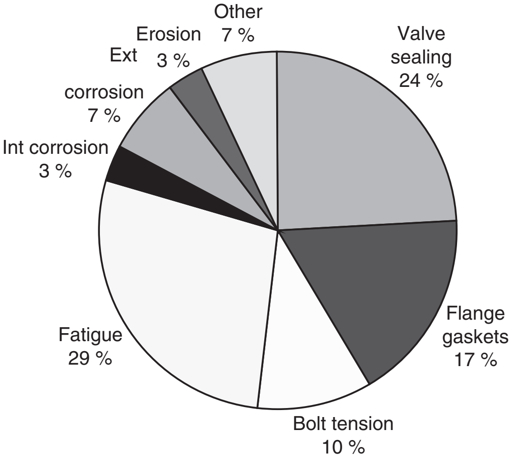

Figure 3. Breakdown of technical faults.

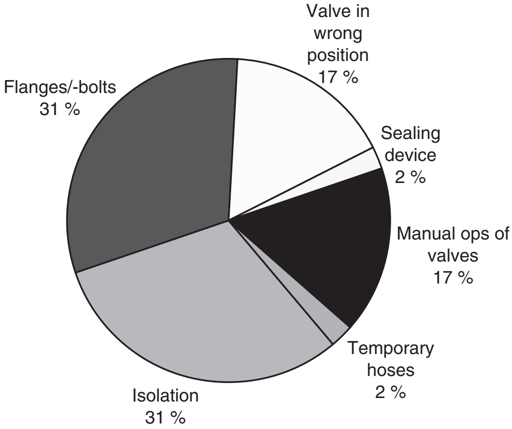

Figure 4. Breakdown of latent errors.

system is not specified or not used, that the specification of the system is not adequate (e.g. too few inspection points) or that the system is not fully functional (e.g. will inspection methods not detect all potentially critical cracks).

- Technical failures of the system – This is relevant only for technical barrier systems and will basically cover the technical "unreliability" of the system.
- Human errors – This covers human errors related to preparation for and performance of the work, e.g. errors in documentation used as basis for performing the work, failure to perform the work according to a described procedure etc.

The fault trees defined for the individual barrier systems largely follow this overall structure. One example is presented in Figure 5.

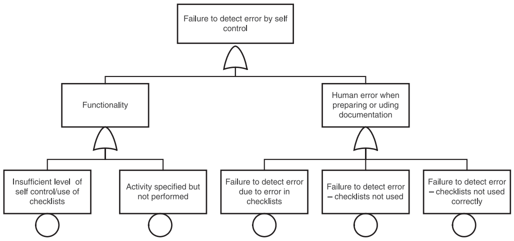

Figure 5. Fault tree for the barrier system 'self control'.

3.5 *Industry average frequencies and probabilities*

There are two sets of industry average data that go into the risk modelling:

- Initiating event frequencies
- Basic event probabilities for fault trees

The main basis for the initiating event frequencies is actual leaks that have been reported to Petroleum Safety Authority (PSA) for the period 2001 to 2005. The investigation reports have been reviewed and the causes of the leaks identified. This is used to establish a breakdown of the total leak frequency on causal factors.

Technical failures can be directly linked to equipment counts, followed by adjustments based on RIF scoring for the specific installation. For operational failures, the calculation can in principle be performed as follows:

$$F_{IE} = N_{WO} \cdot P(IE|WO)$$

where F_{IE} is the frequency of the Initiating Event, N_{WO} is the number of Work operations per year and P(IE|WO) is the probability of the Initiating Event occurring when performing the Work operation. In practice, we have however also arrived at a possible simplified approach that can be used to link the number of work operations to the equipment count. This is done to enable use of the methodology even with limited availability of data on the number of operations.

The basic events in the fault trees are of a varying nature and the probabilities will therefore also have to be determined from a variety of sources. Data on technical failures will be based on platform specific information, from reliability studies of the technical systems or from other sources (in the same way as in QRAs today). Human error probabilities have however been gathered as part of this project and proposed data are presented.

In order to prepare a basis for quantifying the effects of human error, a number of data sources have been reviewed and compared. The purpose of the literature search has been to establish a set of recommended data which can be applied in the modeling of barriers. The following data sources have been reviewed:

- Swain and Guttman (1983)
- Reason (1997)
- Blackman and Gertman (1994)
- Kirwan I (1994)
- Kirwan II (1998)

The total number of available data sources is rather limited, and the textbooks and reports that have been subject to review vary with respect to industrial background and scope. In addition, some of the sources are rather old (Swain & Guttman 1983). Still, it is found plausible to base the fault tree data on the listed sources.

3.6 *Risk influence diagrams*

The purpose of the risk influence diagrams is to identify and illustrate the RIFs influencing the probabilities or frequencies of the occurrences of the basic events in the fault trees. The risk influence diagrams were developed by members from the project team and verified in discussions with personnel from oil companies. The development of the RIFs is discussed thoroughly in Aven et al. (2006) and examples from one case study are presented in Sklet et al. (2006).

The framework for identification of RIFs is based on a review, comparison, and synthesis of several schemes of classification of human (abbreviated 'M' for 'man'), technical, and organisational (MTO) factors and experience from the case study. The schemes include classification of;

1. Causes in methods for accident investigations (MTO-analysis, Bento 2001 and TRIPOD, Reason 1997),
2. Organisational factors in models for analysis of the influence of organisational factors on risk like I-RISK (Papazoglou 2003) and WPAM (Paté-Cornell & Murphy 1996, Hokstad et al. 2001),
3. Performing shaping factors (PSFs) in methods for human reliability analysis (HRA), like THERP (Swain & Guttmann 1983), CREAM (Hollnagel 2006), SLIM-MAUD (Embrey 1984), and HRA databases (CORE-DATA, Gibson & Kirwan 1998).

3.7 *Weighting of RIFs*

Weighting of the RIFs is an assessment of the effect (or importance) the RIFs has on the frequency or probability of occurrence of the basic events. The weights of the RIFs correspond to the relative difference in the frequency or probability of occurrence of an event if the status of the RIF is changed from A (best standard) to F (worst practice).

The weighting of the RIFs is done by expert judgments in work shops. The assessments of weights were based on an individual assessment of the attendees of the workshops prior to a general discussion and a common agreement of the importance.

Table 2. Generic scheme for scoring of RIFs.

Score	Explanation
A	Status corresponds to the best standard in industry
B	Status corresponds to a level better than industry average
C	Status corresponds to the industry average
D	Status corresponds to a level slightly worse than industry average
E	Status corresponds to a level considerably worse than industry average
F	Status corresponds to the worst practice in industry

A five point scale (from high importance to low importance) is applied. Quantitatively, the RIFs were given relative weights on the scale 10 – 8 – 6 – 4 – 2. Finally, the weights were normalized as the sum of the weights for the RIFs influencing a basic event should be equal to 1.

The weighting process is discussed thoroughly in Aven et al. (2006).

3.8 *Scoring of RIFs*

Scoring of the risk influencing factors implies to assign a score to each identified RIF in the risk influence diagrams. Each RIF is given a score from A to F, where score A corresponds to the best standard in the industry, score C corresponds to industry average, and score F corresponds to worst practice in the industry (see Table 2). The six-point scale is adapted from the TTS (Technical Condition Safety) project (Thomassen & Sørum 2002).

There are two principally different approaches to RIF scoring and quantification:

- Specific studies tailored to the needs of the BORA methodology
- Use of existing studies where applicable, supplemented with additional studies where needed

The conclusion from the case studies is that a combination of existing studies and additional studies is the most effective basis for performing the scoring. The following is summarized from the case studies:

- The most extensive information can be found from the TTS reports. In particular, this provides information related to technical Basic Events, especially for the consequence barrier systems. However, the TTS reports do not only give information for technical systems; there is also information related to operational Basic Events.
- Use of Expert Judgment for the scoring of operational basic events turned out to be a very efficient process with the additional benefit that it involves operational personnel. Expert Judgment is thus a

very good supplement to the TTS reports and the two data sources together give a good basis for performing the analysis.
- RNNS questionnaire information (PSA 2006) is more uncertain. The adjustment factors tend to be smaller than what is found when using the other data sources. However, this could be a useful additional data source and if more specific questions were included in future survey, the applicability of this data source could be improved.
- As regards MTO investigations, this is the most limited data source and it has also turned out to be difficult to use the data in a systematic manner.

3.9 *Adjustment of average frequencies/probabilities*

The industry average probabilities/frequencies used in the quantitative analysis are adjusted in order to assign platform specific values allowing for platform specific conditions of the RIFs. The industry average probabilities/frequencies are revised based on the risk influence diagrams through an assessment of the weights and score of the RIFs.

The principles used for adjustment of the industry average data were discussed thoroughly in Aven et al. (2006).

3.10 *Installation specific values*

The final step is to calculate the risk by use of the generic model, generic data and platform specific data. Figure 1 illustrated the types of information that is generic and platform specific respectively:

- The structure of the model as such is generic, in the sense that there are generic work operations and equipment packages, initiating events, BBDs, fault trees and what RIFs influence the various factors.
- The generic data that go into the quantification of the model are indicated in green/light grey in the figure. This includes Initiating Event frequencies, Fault tree probabilities (Basic Event probabilities) and RIF weights.
- Platform specific data are shown in red/dark colour. This includes the number of work operations per year, equipment count and platform specific RIF scores.

4 ANALYSIS OF HYDROCARBON LEAK RISK

Analysis of hydrocarbon leak risk has traditionally been a calculation of the number of potential leak sources with a generic leak frequency for equipment types. Optionally, the outcome is compared to the leak statistics for the installation in question, if such statistics is available.

Traditionally, no adjustment has been performed based on the number of work operations, in spite of the fact that more than 50% of leaks above 0.1 kg/s leak rate are due to operator intervention (Vinnem et al. 2006). It may on the other hand be argued that leak frequencies due to operational errors implicitly are included, if the resulting leak frequencies are adjusted according to the overall leak frequency for the installation.

On an overall level, this may be true. But possible common cause failures of barriers cannot be analysed in detail, when all leaks are analysed as if they had technical causes. Possible combination of barrier function failures which for instance lead to loss of containment as well as may cause loss of the barrier integrity function would be extremely critical, but can not be addressed, unless operational causes for leaks are analysed explicitly.

It has also been shown that there are considerable variations between operators and individual installations with respect to how dominating hydrocarbon leaks during operator intervention, see Vinnem et al. (2007). This implies that it should be essential for individual operators and installations to consider explicitly the expected number of leaks due to equipment failure and operator intervention.

5 CONCLUSIONS AND RECOMMENDATIONS

The overall conclusion from the cases studies is that the methodology that has been developed and tested show a promising potential for application in practical studies of risk associated with process facilities and their operation. We see two key objectives that a new approach needs to address in order to be useful in such a context:

- The approach must address some of the weaknesses currently found in QRAs. Examples of such weaknesses are causal analysis (especially for releases) and also how they are able to reflect the influence of operational, organisational and human aspects. This should also include the ability to reflect any common cause failures relating to these aspects.
- Secondly, the work associated with using the approach in practical applications must be reasonable compared to the benefits that the new methodology provides.

It is considered that the methodology does cover some of the weaknesses identified in Item 1. It is quite clear that more experience needs to be gained with use and that the details need to be developed further through practical usage, but it is considered that the basic framework is a sound and reasonable approach for addressing these issues.

As regards the work associated with implementing this approach into practical studies, it is our opinion that it is possible to implement the key elements of this into QRAs without excessive additional amount of work. The experience from performing the case study work is that the work required to establish platform specific scores related to both technical systems and organizational/human factors is likely to be more limited than what was expected before the work was started.

ABBREVIATIONS

BORA	Barrier and Operational Risk Analysis
BBD	Barrier Block Diagram
FTA	Fault Tree Analysis
HRA	Human Reliability Analysis
IE	Initiating Event
MTO	Man, Technology and Organisation
PSA	Petroleum Safety Authority [Norway]
PSF	Performance Shaping Factor
QRA	Quantified Risk Analysis
RIF	Risk Influencing Factor
RNNS	Risk level project
TTS	Technical condition safety

REFERENCES

Aven, T., Sklet, S., and Vinnem, J.E. 2006. Barrier and operational risk analysis of hydrocarbon releases (BORA-Release); Part I Method description, Journal of Hazardous Materials, A137, 681–691

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

Blackman, HS and Gertman, DI., 1994. Human Reliability and Safety Analysis Data Handbook, John Wiley & Sons, 1994

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. and Kirwan B., 1998. Development of the CORE-DATA database, Paper dated 23.04.98, University of Birmingham, UK

Haugen et al. (2007) BORA methodology report, Report 200254-07, 29.1.2007, Preventor AS, Norway

Hokstad P, Jersin, E. and Sten, T. (2001) A risk influence model applied to North Sea helicopter transport. Reliability Engineering and System Safety, 74, 311–322

Hollnagel, E., 2006. Cognitive CREAM

HSE. 2006, HCR website

Kirwan, B., 1994. A Guide to Practical Human Reliability Assessment, Taylor & Francis Ltd., 1994.

Kirwan, B., 1998. Human Factors & Human Reliability in Offshore Systems, Course arranged at SINTEF, Trondheim, May 11–13 1998

Nilsen, T., Jacobsen, G.S. and Aven, T., 2000. Requirements and principles for cause analysis in QRA – with applications ESREL, Edinburgh, pp. 641–646

Miles, R. 2004. Private communication with Robert Miles, HSE

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. and 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

PSA, 2006, Risk Level on the Norwegian Continental Shelf, Main report 2004, Phase 5, PSA report 06-02, 28.4.2006

Reason, J., 1997. Managing the Risks of Organizational Accidents, Ashgate Publishing Company, Burlington, 1997

Sandøy, M., et al. Risk-Based Well Control Planning: The Integration of Random and Known Quantities in a computerized Risk Management Tool, SPE 68447, Presented at SPE/ICoTA Coiled Tubing Roundtable, Houston, Texas, 7–8 March 2001

SfS, 2004, 'Working together for safety' web page info http://www.samarbeidforsikkerhet.no/index.html?infoPage=oppslag.html&id=2&siteID=&frameID=3&languageCode=EN

Swain, AD and Guttmann HE., 1983. Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications, U.S. Nuclear regulatory commission report NUREG/CR-1278, SAND80-020, August 1983

Thomassen, O. and Sørum, M. 2002. Mapping and monitoring the technical safety level. Presented at Sixth International Conference on Health, Safety and Environment, March 18–20, 2002, Kuala Lumpur, Society of Petroleum Engineers, SPE

Torjussen, C., 2003. Activity indicator for gas leaks – which data are available and how can we make use of them, Master thesis University of Stavanger, 2003

Vinnem, J.E. et al. 2003a, Risk assessments for Offshore Installations in the Operational Phase. Presented at ESREL2003, Maastricht, The Netherlands

Vinnem, J.E. et. al. 2003b, Operational Risk analysis – Total analysis of physical and non-physical barriers, BORA pre project report, 16.10.2003

Vinnem, J.E. 2004a, Integrated barrier analysis in operational risk assessment in offshore petroleum operations, paper presented at PSAM7, Berlin, June, 2004

Vinnem, J.E., Veire, G., Heide Knudsen, B., Aven, T. 2004b, A method for developing and structuring risk activity indicators for major accidents, to be presented at ESREL2004/PSAM7 conference, Berlin, June, 2004

Vinnem, J.E., Aven, T., Husebø, T., Seljelid, J. and Tveit, O. (2006) Major hazard risk indicators for monitoring of trends in the Norwegian offshore petroleum sector. *Reliability Engineering & Systems Safety,Volume 91, Issues 7, July 2006*, 778–791

Vinnem, JE., Seljelid, J., Haugen, S. and Husebø, T., 2007. Analysis of Hydrocarbon Leaks on Offshore Installations, paper to be presented at ESREL2007, Stavanger, Norway 25–27 June, 2007