Integrated Barrier Analysis in Operational Risk Assessment in Offshore Petroleum Operations

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Abstract

The BORA project is aimed at detailed and quantitative modeling of barrier performance, including barriers to prevent occurrence of initiating events, and barriers to avoid or reduce consequences. Challenges related to the modeling are reviewed, and some solutions are suggested.

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 to some extent 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 disrupture of stable production. The occurrence of these leaks is a clear indication that system and human defences 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.

In a paper presented at ESREL 2003 [1], 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 [2].

2 Objectives of BORA project

A case study with complete modeling and analysis of barriers on offshore production installations is being 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, together with effective modifications and configuration changes.

The analysis will be quantitative as far as is possible. Barriers are in general characterised by reliability/availability, functionality and robustness. 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.

3 Overview of Current Approaches and future Needs

Several R&D projects are being conducted in the Norwegian offshore petroleum industry addressing performance of defenses/barriers. Most of these are internal projects, but a few are openly available, see [3], [4] and [5]. 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/defenses [6].

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 [7]. Other projects that have provided useful input are:

- Several projects addressing non-physical barriers
- MTO-structured accident and incident investigations
- Working group in 'working together for safety' project addressing terminology for physical and non-physical barriers [8]
- Cause analysis for process leaks [9]

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 [5], which is also used in the BORA project.

4 Challenges with Modeling of Containment Barrier

Modelling the risk of hydrocarbon leaks in quantitative risk analysis has traditionally been related to generic frequency analysis. Based on the amount and type of process equipment combined with historic leak frequencies for such equipment, the frequencies of loss of containment for each process segment, area and the installation as a whole have been estimated. In such a generic approach important information is left out from the model, both related to the direct causes of the leak as well as the underlying conditions which influence the possibility of experiencing loss of containment.

A major objection against the offshore risk analysis has been its lack of ability to support the operations people with answers to questions like; what is the:

- Effect on the leak frequency of postponing a certain maintenance activity?
- Effect of inhibiting process sensors?
- Effect of factors such as training, competency, complexity and manning?

The containment barrier must therefore be broken down to a level where operational factors are explicitly visualised and modelled. However, this is a challenging task. On the one hand we want to model all the major aspects which influence the frequency of loss of containment. On the other hand, this soon makes the model so complex and extensive that it will not be applied in actual analysis work.

Traditionally, the event modelling in QRA starts with loss of containment as the initiating event, and the barriers to limit the potential consequences of the leak are modelled. In the BORA project we want to visualise the barrier elements in place to prevent the leak itself. For this purpose 'barrier block diagrams' have been developed for different conditions which may cause loss of containment. For the case 'loss of containment due to incorrectly fitted equipment', see Figure 1.

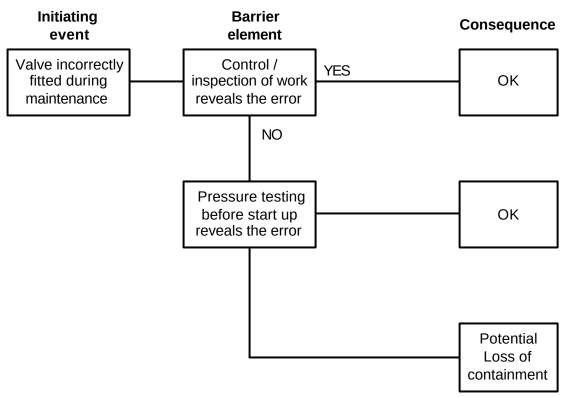

Figure 1 Barrier block diagram –'incorrectly fitted equipment'

In the further work, the different barrier elements to prevent loss of containment will be modelled by using fault trees, and the barrier block diagrams will be linked with the event trees which model the consequences of a leak. The barrier elements will also be related to activities that are being carried out.

5 Challenges with Modeling of Consequence Barriers

The BORA project is modelling four consequence barrier functions: Avoid Ignition, Reduce Release, Avoid Escalation and Prevent Fatalities. They can all be activated by automatic systems or by manual operations. Gas detection is for example a key factor for 'Avoiding Ignition', and detection can either be by automatic systems or personnel doing maintenance or other activities in the area or by others that are just passing by. The main difference between detection modes is the time to detection. The barriers are not independent of each other. Gas detection is both a part of 'Avoid Ignition' and 'Reduce Release'. The ignition can occur either before or during activation of the different barriers, and the probability of ignition is dependent on the systems that have been activated at the time of ignition. This is a challenging sequence to model. The fact that the probability of ignition is also dependent on the initial size of the leak, leak point and weather conditions, is complicating the picture even more.

A coarse block diagram is presented in Figure 2, showing the main barrier elements and possible ignition points. All these combinations are modelled in the BORA project.

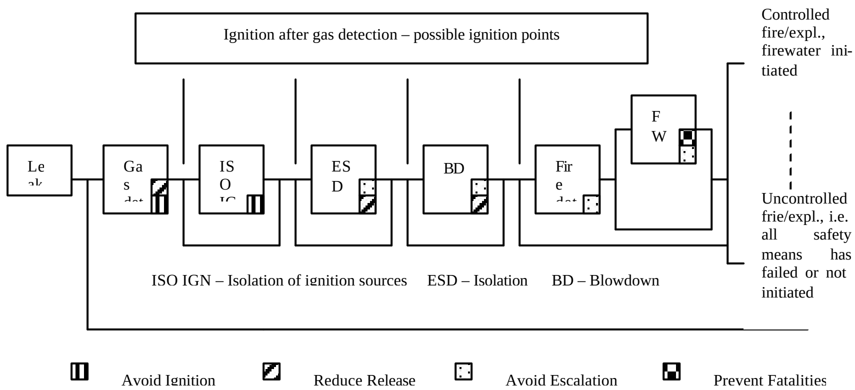

Figure 2 Block diagram – main barrier elements and ignition points

The sequences of the different barrier elements and ignition points are modelled in event trees combined with detailed fault trees for every branch, modelling manual and automatic activations for different operational modes. The function of some of the barriers is very dependent on the current operation mode. Manual detection will for example be dependent on the presence of personnel in the module, and their awareness of possible leaks.

6 Challenges relating to Incorporation of Performance Influencing Factors

Performance influencing factors will not be included explicitly in the fault trees, but this does not mean that such factors are unimportant in the analysis.

It is essential to structure the analysis such that the influencing factors are modelled extensively in the analysis, in a consistent and explicit manner. This is outlined in the following. The basic elements of the fault tree based method we have developed can be formulated in the following way;

a) Identify top events A that summarise essential barrier performance. An example is 'ignition' or 'avoid ignition' given a specific leakage scenario. The event A must be precisely defined – no ambiguity can exist.
b) Establish a deterministic model that links A and events B_i and quantities X_i on a more detailed level. A fault tree is an example of such a model.
c) Specify a set of operational and management factors F_i that could influence the performance of the barriers, and which have not been included in the fault tree model. Examples of such factors are the quality of the maintenance work, the level of competence and the adequacy of organisation.
d) Probability specifications $P(B_i| \mathbf{F})$, where **F** is the vector of the F_is.
e) Probability calculus to obtain $P(A| \mathbf{F})$.

To implement the framework there are a number of challenges, of which the following are some of the most important:

i. Determine which F factors that should be included in the fault tree. The F factors are fixed, meaning that the probability assignments are conditioned on these factors. If some of the F factors are to be considered unknown to the analyst, these factors need to be included in the fault tree, or the factors should be divided into two categories, reflecting unknown factors on the one hand and some given factors on the other. Such a distinction is made in the SAM-method (Pate-Cornell and Murphy [10] Murphy and Pate-Cornell [11]).
ii. Finding adequate procedures for specifying the probabilities $P(B_i|\mathbf{F})$. These procedures need to be based on models and methods used for barrier performance analyses, such as human reliability analysis.

The work by Papazoglou and Aneziris [12] was considered in the review of possible approaches of human, management and organisational aspects.

7 Concluding Remarks

The project has focus on identification of weaknesses and deficiencies in barriers, especially during execution of operational activities, In this way, the need for reinforcement of existing barriers as well as requirements concerning additional barrier elements can be identified.

The ambition in the project is on quantification of barrier performance, with respect to reliability, vulnerability and effectiveness. This implies that there are considerable challenges to be faced during the execution of the project. The next phase of the work will focus on modelling of factors that influence the performance of barrier systems and barrier elements. This is a further challenging factor.

Acknowledgement

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