

Addressing Dynamic Risk in the Petroleum Industry by Means of Innovative Analysis Solutions

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The importance of Integrated Operations (IO) is rapidly growing in today's petroleum industry. It is being developed to improve capture of real-time safety barrier data and to process, visualize and share this information for closer onshore-offshore collaboration and expert support. Increased capacity in the communication infrastructure (e.g. via fibre optics) and integration and processing of data from various sources enable more accurate methods of risk analysis that would have been previously considered time-costly. For this reason this study addresses the topic of dynamic approach to risk in an IO context by presenting and integrating advanced techniques of hazard identification and risk assessment, such as: DyPASI (Dynamic Procedure for Atypical Scenarios Identification), DRA (Dynamic Risk Assessment) and the Risk Barometer methodology. DyPASI was developed in the EC project iNTeg-Risk. This technique aims to produce complete and updated HAZID process. Atypical accident scenarios, which by definition are deviating from normal expectations of unwanted events or worst case reference scenarios, are identified through a systematic screening of related emerging risk notions. The DRA method aims to estimate updated expected frequency of accident scenarios by means of Bayesian inference. Real time abnormal situations or incident data are used as new information to update the failure probabilities of the system safety barriers, which necessarily affect the overall scenario frequencies and the related risk picture. The Risk Barometer was developed within the Center for Integrated Operations in the Petroleum Industry. It aims to continuously monitor specific indicators measuring the status of critical safety barriers and translate them into risk picture changes. Its result is an intuitive graphical representation of the overall risk level in order to support decision makers in daily operations. The description of these techniques will be accompanied by a preliminary application on a generic case-study, in order to demonstrate the effectiveness of such dynamic approach in risk management and prevention of related major accidents.

1. Introduction

Today offshore oil and gas industry is being revolutionised by new ways of performing and organizing work based on the application of information and communication technology. These innovative approaches have been named Integrated Operations (IO) by the main industry actors and they can be understood as the integration of people, work processes and technology in order to take more appropriate decisions and ensure better execution. This is enabled by the use of real time data, collaborative techniques and expertise crossing disciplines, organizations and geographical locations (Albrechtsen and Besnard, 2013). The aim of IO solutions is not only to increase value creation, but also reduce the risks of a major accident. In particular IO can allow more accurate methods of risk analysis that would have been previously considered time-costly. For this reason this study addresses the topic of dynamic approach to risk in an IO context by presenting and integrating advanced techniques of hazard identification and risk assessment. The description of these techniques will be accompanied by a preliminary application on a generic case-study, in order to demonstrate the effectiveness of such dynamic approach in risk management and prevention of related major accidents.

2. Methodologies addressing dynamic risk

Although several techniques of HAZard IDentification (HAZID) and Quantified Risk Analysis (QRA) have often proven effective in industry, they generally lack of the ability to dynamically update on the basis of real-time information. Thus, three innovative techniques (Figure 1), whose main feature is their dynamicity and capacity to be reiterated and produce updated risk assessment, are applied and evaluated in this work. These techniques are chosen for their potential suitability with IO solutions and related implications.

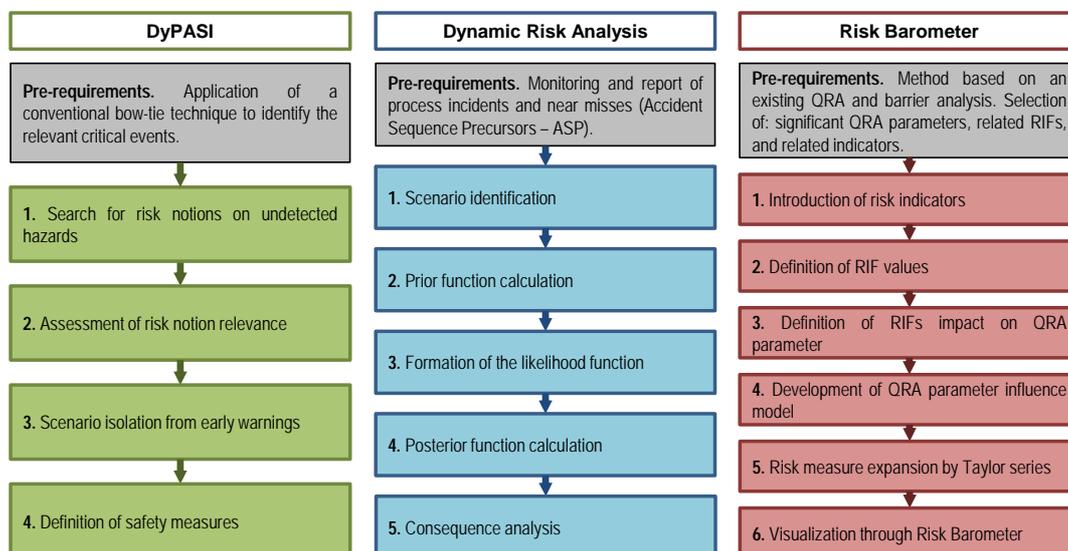


Figure 1: Description of the methodologies (Paltrinieri et al., 2013, Kalatarnia et al., 2009, Okstad et al., 2013).

2.1 Dynamic Procedure for Atypical Scenarios Identification

The Dynamic Procedure for Atypical Scenarios Identification (DyPASI) is based on the development of well-established bow-tie analysis techniques (CCPS, 2008) and can be coupled to them whenever the enhancement or updating of the HAZID analysis is needed. It is a method for the systematization of information from early risk signals related to past accident events, near misses and specific studies (Paltrinieri et al., 2013), in order to identify possible disregarded atypical accident scenarios. As a preliminary activity of this study, DyPASI requires the application of a conventional bow-tie technique, such as the one suggested by the Centre for Chemical Process Safety (CCPS, 2008). Subsequently, DyPASI is applied in four main steps (Figure 1). A more detailed description of the method can be found elsewhere (Paltrinieri et al., 2013).

2.1.1. Step 1

A search for relevant information concerning undetected potential hazards and accident scenarios disregarded by the conventional bow-tie development is carried out. The following search systems are used: MHIDAS, (HSE – United Kingdom), ARIA (French Ministry of Environment), and Google Scholar (Google inc.). Relevant concepts from the IT area of study denominated "Information Retrieval" are exploited, in order to reduce potential information overload in the search activity.

2.1.2. Step 2

Once the necessary information is gathered, a determination is made to understand whether the data are significant enough to trigger further action and proceed with the process of risk assessment. As a support of this process of prioritization, a register collecting the risk notions showing their relative relevance and impact can be obtained.

2.1.3. Step 3

The potential scenarios are isolated from the early warnings gathered and a cause-consequence chain consistent with the bow-tie diagram is developed. This allows for the integration of the pattern of the atypical scenario into the bow-tie of hazards previously identified.

2.1.4. Step 4

The definition of safety measures applied to the elements of bow-tie diagrams is the last step of the procedure. The safety measures are described by safety barriers and related generic safety functions.

2.2 Dynamic Risk Assessment

The Dynamic Risk Assessment (DRA) methodology is based on the development of conventional quantitative risk assessment approaches (NORSOK, 2010) and allows dynamically assessing the frequency of accident scenarios by means of the integration of Bayesian failure updating mechanism. Monitoring and report of process incidents and near misses (denominated Accident Sequence Precursors – ASP) is a pre-requisite of this technique. DRA may be implemented to a selected system in five steps (Figure 1). Nomenclature can be found in section 6. A more detailed description of the method can be found elsewhere (Kalantarnia et al., 2009).

2.2.1. Step 1

The potential scenarios, their consequences, causes and related safety barriers are identified in this first step. A Bow-Tie Analysis is performed at this step to provide a visual representation of consequences, causes and related safety barriers in place to mitigate or control the hazards.

2.2.2. Step 2

Consequence frequency ($f_{cons.}$) is obtained from the product of the bow-tie central event frequency ($f_{c.e.}$) by the conditional probabilities (p_i) encountered on the diagram cut-set leading to the consequence, such as a barrier Probability of Failure on Demand (PFD):

$$f_{cons.} = f_{c.e.} \prod p_i \quad (1)$$

PFDs can be calculated from prior failure functions of barriers, which are our understanding of barriers prior to the start of operation. A probability density function of type Beta can represent failure probability (Vose, 2000) and its mean value is used as conditional probability in the frequency analysis.

2.2.3. Step 3

Process real-time data inferred from the ASPs are used to form a likelihood function. Being data specific numbers within a discrete domain, a binomial distribution is used to represent the likelihood function.

2.2.4. Step 4

A posterior failure function of the safety barriers ($f(p_i|Data)$) is obtained from the prior ($f(p_i)$) and likelihood functions ($g(Data|p_i)$) using Bayesian inference. Bayesian inference is a tool which uses data to improve an estimate of a parameter. The posterior function is the same distribution type as the prior (Beta), but the parameters are updated through the likelihood function. Thus, the posterior function can be derived as follows:

$$f(p_i|Data) \propto g(Data|p_i)f(p_i) \quad (2)$$

2.2.5. Step 5

Consequence analysis is carried out on the scenario in order to estimate the potential consequences of all possible scenarios.

2.3 Risk Barometer

The Center for Integrated Operations in the Petroleum Industry is developing the "Risk Barometer" technique aiming to continuously monitor risk picture changes and support decision makers in daily operations. This technique is influenced by previous analogous methods, such as the ORIM (Organizational Risk Influence Model) (Øien, 2001) and Risk OMT (Risk modelling – integration of Organisational, Human and Technical factors) (Vinnem et al., 2012). As a pre-requirement, the Risk Barometer should be based on an existing Quantified Risk Analysis (QRA), in order to identify the most risk-affecting QRA parameters (e.g. PFDs of safety barriers). Factors describing the condition of barriers (named Risk Influencing Factors) are then linked to QRA parameters. To conclude, a set of risk indicators are introduced to measure the status of the various RIFs. The Risk Barometer can be applied in six steps (Figure 1). Nomenclature can be found in section 6. A more detailed description of the method can be found elsewhere (Okstad et al., 2013).

2.3.1. Step 1

In step 1 risk indicators ($x_{j,k,z}$) are collected. It is required to map risk indicator values by means of a standardized mark scale. For this reason, indicator values collected at time t are translated into standardized marks ($m_{j,k,z}$).

$$m_{j,k,z} = M(x_{j,k,z}) \quad (3)$$

2.3.2. Step 2

Linear weighted sum is used to obtain a single RIF value ($r_{j,k}$). The relative weight of indicators should be determined by the analyst on the basis of the information provided by the plant operator.

$$r_{j,k} = \sum_{z=1}^{Z_{j,k}} w_{j,k,z} m_{j,k,z} \tag{4}$$

2.3.3. Step 3

Linear weighted sum is used for the definition of the impact (r_j) of RIFs on a single QRA parameter. The relative weight of the single RIF should be determined by the analyst on the basis of plant operator information.

$$r_j = \sum_{k=1}^{K_i} w_{j,k} r_{j,k} \tag{5}$$

2.3.4. Step 4

The relation between the total weighted RIF value and the QRA parameter (q_j) is established by means of a linear interpolation.

$$q_j = q_{j,L} + \frac{(r_j - r_{j,L})(p_{j,H} - p_{j,L})}{(r_{j,H} - r_{j,L})} \tag{6}$$

Okstad et al. (2013) recommends the geometric interpolations in case the parameter variation is more than one order of magnitude.

2.3.5. Step 5

A risk measure expansion by a Taylor series allows calculating the risk value (R). The partial derivative of the risk measure ($I^B(j)$ – Birnaum like measure) with respect to the QRA parameter is used.

$$R = R_0 + \sum_{j=1}^J I^B(j) \Delta q_j = R_0 + \Delta R \tag{7}$$

2.3.6. Step 6

The results are visualized by a circular diagram illustrating the risk level with different colours (from white = low risk to dark red = high high risk – Figure 3). In order to show the multiple-attribute nature of the problem, the risk barometer can elaborate both the aggregated risk level of the whole plant and the specific risk of certain areas. Moreover, a plot of risk versus time shows the trend and an alert on the indicators contributing the most to the overall risk is displayed.

3. Representative application

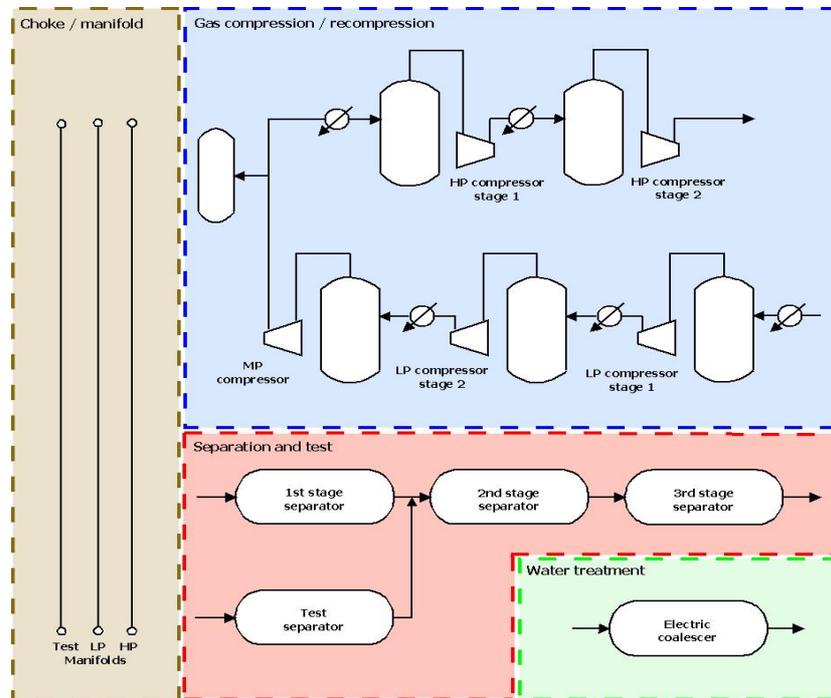


Figure 2: Generic offshore oil production process area

A representative application of the mentioned methodologies was performed on a generic oil production process area located topside of an offshore platform (Figure 2). The process area consists of the following separate modules:

- Choke/manifold
- Gas compression / recompression
- Separation and test
- Water treatment

The modules are not separated by physical barriers and are considered a single "fire area" (main process area). This area is separated from the offloading area by a fire and explosion rated wall.

4. Results

Table 1: Summary of the risk notions identified through DyPASI

	Explosion	Fire	Release	Other	Tot
Disaster	3				3
Accident	8	6		1	15
Incident	4	6	2		12
Mishap	2	1	6		9
Tot	17	13	8	1	

The application of DyPASI highlighted its complementarity with DRA, but did not lead to the identification of specific atypical scenarios. However, the risk notions identified (Table 1 and related studies, e.g. Tugnoli et al. 2013) were used to define fictional ASPs for the application of DRA.

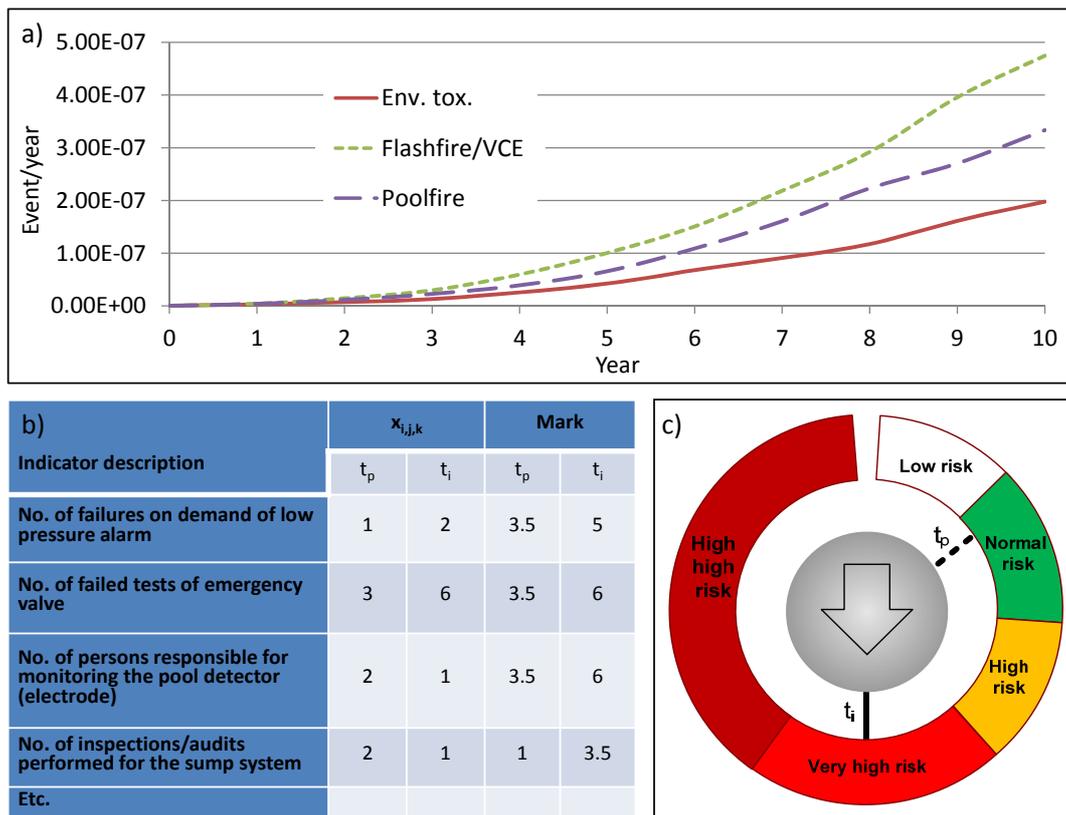


Figure 3: Preliminary results from the application of the three methodologies. a) Expected frequency of environmental damage / toxic effects, Flashfire / VCE and Poolfire calculated by means of DRA for a period of 10 years; b) examples of indicators collected at the time t_p (previous time period) and t_i (instantaneous); c) risk barometer showing the risk level at the time t_p and t_i .

Figure 3a shows the increase of expected frequency of selected accident scenarios calculated by considering these ASPs. A set of indicators defining the status of the safety barriers in the process area was also defined and average values with representative variations applied (Figure 3b). This demonstrated the risk barometer way of working and generating a dynamic risk picture of the plant (Figure 3c).

5. Conclusions

The three techniques were effectively applied to a generic case-study. The only complementarity identified was between DyPASI and DRA. The comparison of DRA and Risk Barometer highlights overlaps and the different strategies adopted in the assessment of the risk picture. DRA demonstrated its effectiveness in real-time risk evaluation. However, being the Risk Barometer developed within the IO center, it was proven to be the most suitable technique in this context. In fact, it is based on indicators that can be automatically collected from the system, in order to give a real-time response. Moreover, it addresses the issue of the visualization of results, in order to share information across geographical, organizational and discipline boundaries as a support for critical decision-making.

6. Nomenclature

Table 2: Description of equations symbols

Symbol	Description	Symbol	Description
f_{cons}	consequence frequency	$W_{j,k}$	Standardized RIF weight
$f_{c.e.}$	bow-tie central event frequency	p_j	Value of QRA parameter at time t
p_j	conditional probability	$p_{j,L}$	Lowest foreseeable QRA parameter value
$f(p_j)$	safety barrier prior failure function	$p_{j,H}$	Highest foreseeable QRA parameter value
$f(p_j Data)$	safety barrier posterior failure function	$r_{j,L}$	Lowest possible RIF value
$g(Data p_j)$	likelihood function	$r_{j,H}$	Highest possible RIF value
$m_{j,k,z}$	Indicator standardized mark	R	Value of risk
$M(x)$	Function translating indicator into standardized mark	R_0	Value of risk at a reference point
$x_{j,k,z}$	Risk indicator value	I	Total number of QRA parameters
$r_{j,k}$	RIF value	$I^B_{(j)}$	Birnbaum like measure for p_j
$K_{j,k}$	Number of indicators per RIF	Δp_j	$p_j - p_{j,0}$
$w_{j,k,z}$	Standardized indicator weight	$p_{j,0}$	Value of pi at a reference point
r_j	RIF impact on QRA parameter	ΔR	$R - R_0$
J_j	Number of RIFs per QRA parameter		

References

- Albrechtsen E., Besnard D., 2013, Oil and Gas, Technology and Humans. Ashgate, Farnham, UK.
- CCPS, 2008, Guidelines for Hazard Evaluation Procedures, AIChE, New York, USA.
- Kalantarnia M, Khan F, Hawboldt F., 2009, Dynamic risk assessment using failure assessment and Bayesian theory, Journal of Loss Prevention in the Process Industries, 22, 600–606.
- NORSOK, 2010, STANDARD Z-013, Risk and emergency preparedness analysis. Norwegian Technology Centre, Oslo, Norway.
- Øien K., 2001, A framework for the establishment of organizational risk indicators, Reliability Engineering & System Safety, 74(2), 147-167.
- Okstad E. H., Hauge S., Tinmannsvik R. K., 2013, Proactive indicators for managing major accident risk in integrated operations. SINTEF F24087. SINTEF Technology and Society, Trondheim, Norway.
- Paltrinieri N., Tugnoli A., Buston J., Wardman M., Cozzani V., 2013, DyPASI methodology: From information retrieval to integration of HAZID process, Chemical Engineering Transactions, 32, 433-438.
- Tugnoli A., Cozzani V., Padova A. D., Barbaresi T., Tallone F., 2013, Reducing the consequences of accidental fires in oil & gas facilities: A risk-based procedure for identification of the fireproofing zones, Chemical Engineering Transactions, 32, 103-108.
- Vinnem J.E., Bye R., Gran B. A., Kongsvik T., Nyheim O.M., Okstad E.H., Seljelid J., Vatn J., 2012, Risk modelling of maintenance work on major process equipment on offshore petroleum installations, Journal of Loss Prevention in the Process Industries, 25(2), 274-292.
- Vose, D., 2000, Risk Analysis: a Quantitative Guide, 2nd Ed J Wiley Chichester, UK.