A case of dynamic risk management in the subarctic region

Nicola Paltrinieri
Norwegian University of Science and Technology NTNU, Trondheim, Norway
SINTEF Technology and Society, Trondheim, Norway

Tor Olav Grøtan
SINTEF Technology and Society, Trondheim, Norway

Marta Bucelli
Università di Pisa, Italy
SINTEF Technology and Society, Trondheim, Norway

Gabriele Landucci
Università di Pisa, Italy

ABSTRACT: A newly installed Floating Production Storage and Off-loading unit (FPSO) recently started its production from the first oil field in the Barents Sea. This is a climatically sensitive area with increasing maritime activity and scarce onshore infrastructure. Due to potential lack of knowledge on intertwining between new technologies and environment, risk of hidden, dynamic and emergent (h/d/e) scenarios cannot be excluded. However, resilient functioning may allow dealing with such risks. Quasi-real-time techniques for dynamic assessment of human and environmental risks may be applied over the life cycle of the platform. Such techniques can be exploited as a source for progressive learning and refinement of risk evaluation in a deeper sense. A re-orienteering potential can be unleashed by integrating and systematizing additional aspects into the decision-making procedure. The quasi-real-time technique denominated Risk Barometer was applied to this case as representative example. This contribution provides an overview of how dynamic risk assessment would allow assessing risk variation. An approach to derive risk-related knowledge from resilient functioning ("Pulse of Risk" – PoR) is also introduced. The PoR approach is used to re-orient and re-initialize dynamic risk management. This would support integration of not only exogenous information, but also endogenous conditions, for comprehensive safety management and guarantee of protection against environmental damage and harm to humans.

1 INTRODUCTION

The Barents Sea (subarctic region) is a climatically sensitive area with increasing maritime activity and scarce onshore infrastructure. The installation of Floating Production Storage and Off-loading units (FPSOs) in this region may hide the emergence of unexpected risks due to the intertwining of new technologies and extreme (but fragile) environment.

An FPSO in this region would need to be equipped and built for meeting high safety standards. Specific barrier management strategy and a barrier status panel supporting the related decision-making may be employed. The purpose of the panel would be to provide an overview of the status of the barrier functions and elements in the area to protect. Indicators and modelling structures, used as baseline for the panel, may allow further analysis and aggregation of the information collected, reducing uncertainty over time.

Quasi-real-time techniques for dynamic assessment of human and environmental risks may be applied over the life cycle of the platform. In particular, the application of the Risk Barometer approach may represent a valuable option (Hauge, Okstad et al., 2015).

The Risk Barometer focuses on the analysis of critical safety barriers in an industrial system. It assesses the performance of safety barriers by means of specific sets of indicators and relates it to the overall risk picture. This allows for evaluation of possible risk fluctuation. Results are visualized and shared in different sites, in order to provide important decision support. For instance, it would allow both operators to define daily planning on an oil and gas platform and engineers to discuss medium-term maintenance plans.

Such technique may be also exploited as a source for progressive learning and refinement of risk evaluation in a deeper sense. Experience of system deviations, e.g. unwanted events and equipment tests, may be gained by the operators but escape formalization. Significant changes in external conditions may also escape attention. A re-orienteering potential can be unleashed by integrating and systematizing additional aspects into the decision-making procedure. Key aspects are sensitization into new implications of both existing and additional information, and the organization of (collective) attention. This enhances the benefit from the available online and self-learning tools for data collection (Grøtan and Paltrinieri, 2016).

2 FPSO IN THE SUBARCTIC REGION

2.1 *Oil field*

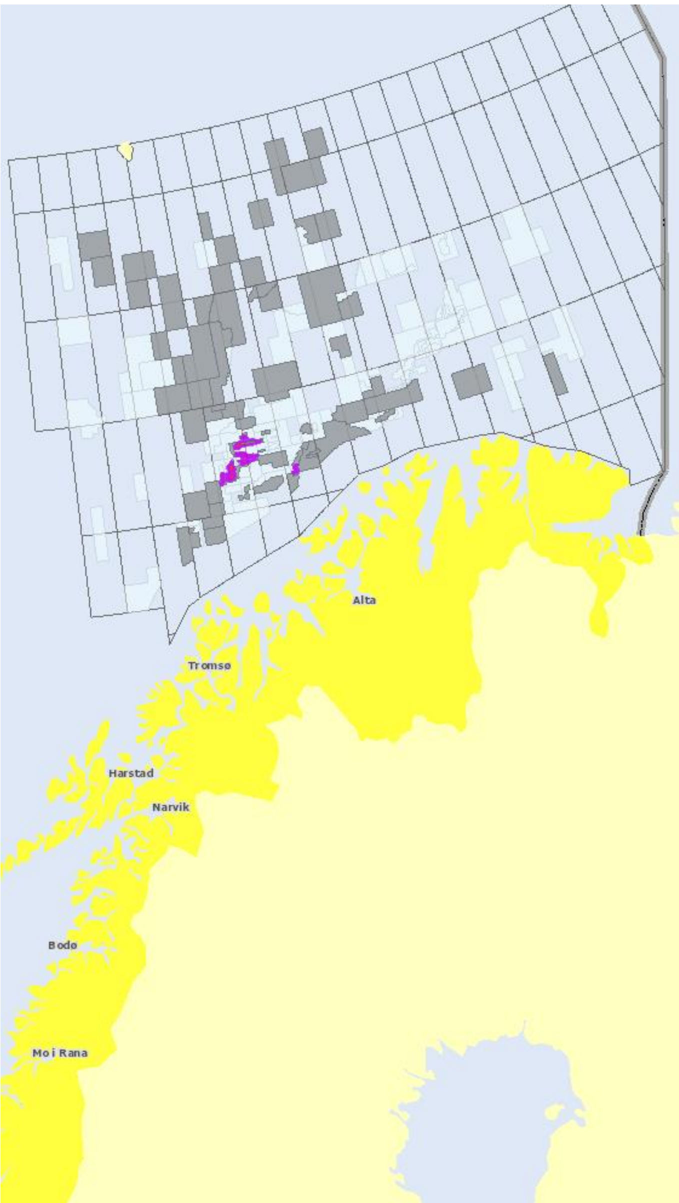

Figure 1. Oil fields in the Barents Sea (grey and purple represents respectively "Licensing" and "Fields and Discoveries" (NPD, 2015)

The Barents Sea is relatively shallow and free from ice during the year, due to high salt level and warm Gulf Stream currents from the Atlantic Ocean. This improves the biodiversity of its ecosystem.

In fact, the Barents Sea and the Kara Sea belong to one of the Marine Ecoregions included in the WWF Global 200 (Olseon and Dinerstein, 2002). The ecoregion supports abundant fish stocks as well as high concentration of nesting seabirds and a diverse community of sea mammals (Larsen, Nagoda et al., 2004).

WWF biologists from Russia and Norway defined the Norwegian coast and Tromsø bank as a high priority area for the maintenance of biodiversity. This was assessed based on the following criteria (Larsen, Nagoda et al., 2004):

- Naturalness;
- Representativeness;
- High biological diversity;
- High productivity;
- Ecological significance for species;
- Source area for essential ecological processes or life-support systems;
- Uniqueness; and
- Sensitivity.

2.2 *Installation*

A FPSO unit in the Barents Sea should ensure safe and reliable production in the harsh conditions in the Barents Sea. FPSOs may have on board fully processing facilities, with stabilized crude oil stored in the cargo tanks. This may be directly offloaded from the FPSO to shuttle tankers through an offloading system. Power issues may be overcome by means of supply from the shore via underwater power cables and integration with on-board power generation. It is possible to identify seven main areas on a FPSO (fig. 2):

- Process Area;
- Main Deck Area;
- Riser Area;
- Utility Area;
- Central Shaft;
- North Shaft;
- Living Quarter.

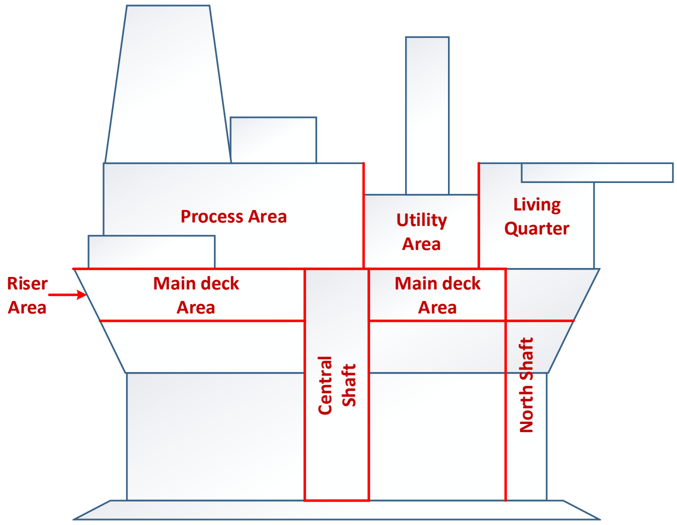

Figure 2. Main areas on a FPSO (Hansen, 2015)

2.3 *Need for dynamic risk management*

Hasle, Kjellén et al. (2009) warn about a series of environmental and safety challenges related to oil and gas exploration in the Barents Sea, such as the risk of oil spills. Extreme environmental conditions, such as low temperatures, long periods of darkness and scarce onshore infrastructure, represent operational challenges potentially increasing the frequency of accidents. Such events may lead to consequences for the environment and subsistence of economy activities. Moreover, they may represent important economic and reputation losses (Kyaw and Paltrinieri, 2015), due to the increased costs of remedial action, the media coverage and the possibility of a moratorium on petroleum activities in that area.

Such issues, associated with potential lack of knowledge about the ecosystems in the Arctic, their vulnerability to petroleum activities, which themselves are conducted with relatively new technologies, may lead to hidden, dynamic and emergent (h/d/e) risks. The notion of h/d/e is used to address risks that may be "unknown" in any sense, i.e. risks that are ignored, forgotten, misunderstood or underestimated, stemming from dynamism and emergence and accommodating both ontological and epistemological uncertainty (Grøtan and Paltrinieri, 2016).

H/d/e risks are endogenous and relate to both dynamics between the "inside" and the "outside". They involve new challenges related to scientific knowledge, risk management methods, practical competence, regulation and governance.

For instance, the Norwegian Petroleum Safety Authority (PSA) requires “establishing and maintaining barriers so that the risk faced at any given time can be handled by preventing an undesirable incident from occurring or by limiting the consequences should such an incident occur” (PSA, 2013).

To better understand this, PSA gives the following definitions:

- Barrier: technical, operational and organizational elements which are intended individually or collectively to reduce possibility/ for a specific error, hazard or accident to occur, or which limit its harm/disadvantages.
- Barrier element: Technical, operational or organizational measures or solutions which play a part in realizing a barrier function.
- Barrier function: The task or role of a barrier. Examples include preventing leaks or ignition, reducing fire loads, ensuring acceptable evacuation and preventing hearing damage.

Specific strategies of integrated barrier management may be defined to provide an overview of all barriers in place and prevent/ mitigate risk on a FPSO in the Barents Sea. This would allow controlling risk in daily operations. Such strategy is based on the following steps (Hansen, 2015):

1. Agree on concepts & definitions
2. Establishing the context and an area division
3. Identifying major accident hazards
4. Identifying barrier functions (and sub-functions) to mitigate the risk identified in step 3
5. Identifying barrier elements for each barrier (sub)function
6. Identifying performance requirements for each barrier element
7. Identifying verification activities for the performance requirements of each barrier element

Verification activities include the collection of indicators addressing technical, operational and organizational performance of barrier elements. Results of this monitoring process are visualized in a barrier status panel and will support critical decision-making.

Such approach may be partially in accordance with the Dynamic Risk Management Framework (DRMF) defined by Paltrinieri et al. (Paltrinieri, Khan et al., 2014). The objective of DRMF is assessing and metabolizing information on potential accident scenarios, in order to continuously improve the current risk picture and limit uncertainties in the management of such risk.

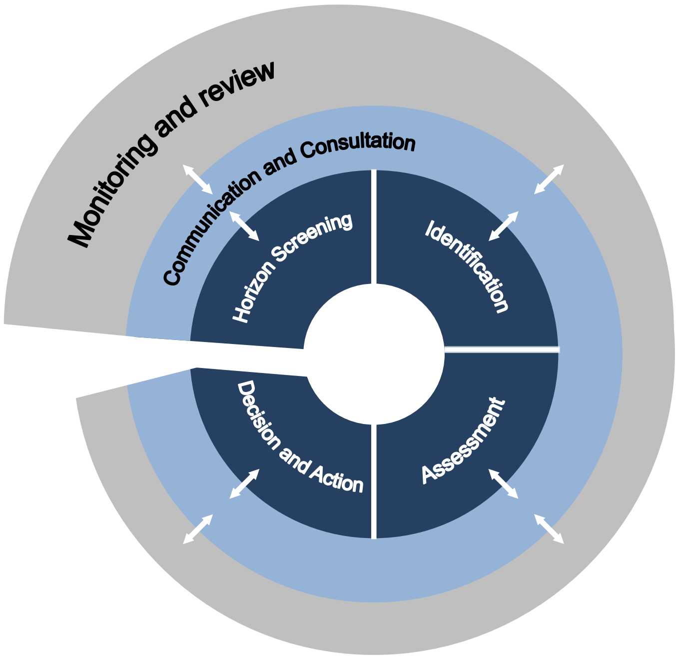

Figure 3. Representation of the Dynamic Risk Management Framework – DRMF (Paltrinieri, Khan et al., 2014).

However, a barrier panel normally would not assess risk, nor reach the core of DRMF with such information update on the barrier performance. In fact, following the DRMF allows for integration of information on potential unknown unknowns (accident scenarios that we are not aware we do not know).

Increased awareness of h/d/e risks hypothetically leads to alternation of learning and decision phases: Horizon Screening, Hazard Identification, Assessment and final Decision/Action are the steps needed to thoroughly evaluate the risks associated to potential accident scenarios. There is no end to the process, but continuous reiteration, in order to keep track of changes and process them for more effective and dynamic management of risk.

Moreover, emergence and dynamism are, in a wide sense, the intrinsic premises for resilience itself. Continual performance variability due to intrinsic adaptations, easily ignored when "nothing" happens, is the norm rather than the exception. This is in line with Karl Weick's characterization of high reliability organizations: "when nothing happens, a lot is happening" and "safety is a dynamic non-event" (Weick, 2009).

The potential scale of manifest change implied by the concept of resilience is wide. Generally speaking, it ranges between a "bounce back" from disturbance back to a "nominal" state, and a "bounce forward" to a new state of equilibrium, encompassing a fundamental change in underlying functioning (Comfort, Boin et al., 2010).

Any assessment of resilience, and especially the risk implied by its presence, is a moving target, always embedded in uncertainty – it is assumed that resilience implies a potential change of operating conditions and characteristics of a system, which may have an impact on risk.

For this reason, it is our belief that a FPSO in the Barents Sea is a good example of an industrial installation that could highly benefit from a structured framework for dynamic risk management, which proactively integrates technical, operational and organizational factors in the continuous refinement of the system risk picture.

3 DYNAMIC RISK ASSESSMENT

The Risk Barometer methodology was preliminarily applied to this case. The method is based on the definition and real-time monitoring of relevant indicators, in order to continuously assess the health of safety barriers and evaluate their probability of failure. Such indicators monitor not only the technical performance of barriers, but also the associated operational and organizational systems. In this way, the Risk Barometer aims to capture early deviations within the organization, which may have the potential to facilitate barrier failure and accident occurrence. Further description of the method is reported elsewhere (Paltrinieri, Hauge et al., 2014, Paltrinieri and Hokstad, 2015).

3.1 *Definition of barriers*

A set of "barrier grids" defined for a FPSO (Hansen, 2015) were used as baseline for modelling. The barrier grids are logic diagrams resembling the bow-tie diagram. They illustrate the relationship between identified Defined Situations of Hazard and Accident (DSHAs) and barrier functions for each of the areas shown in figure 2.

Such barrier grids were modified in order to suit the specific requirements of the Risk Barometer. A generic representative example is shown in figure 4.

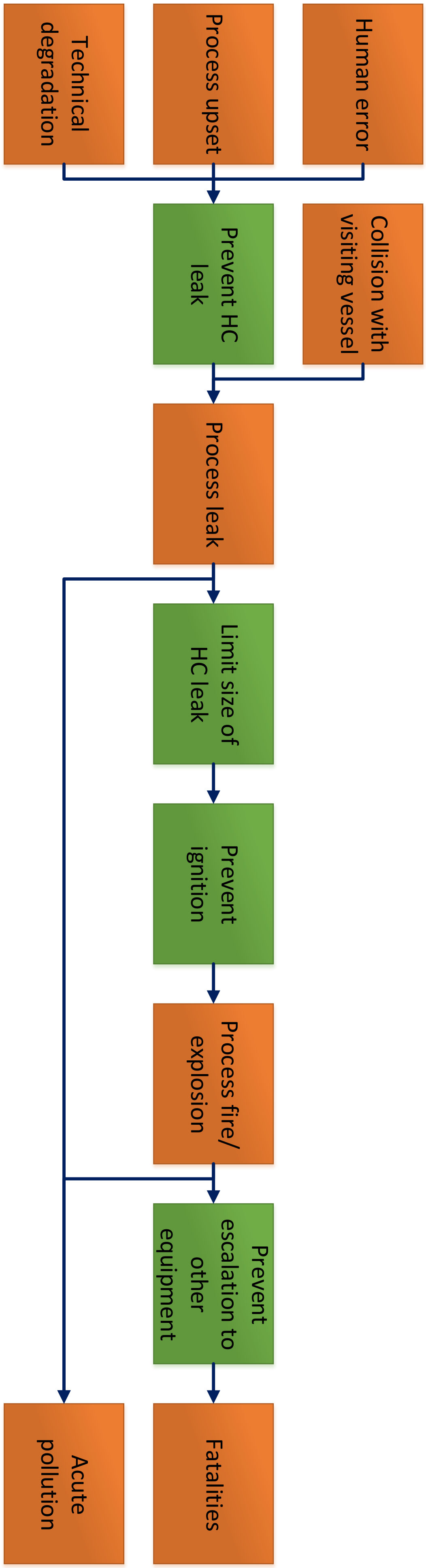

Figure 4. Representative example of FPSO barrier grid modified for the Risk Barometer. DSHAs and barrier functions are represented respectively by the orange and green colors

Each barrier function is also decomposed into sub-functions and elements by means of a "barrier tree", as shown in figure 5.

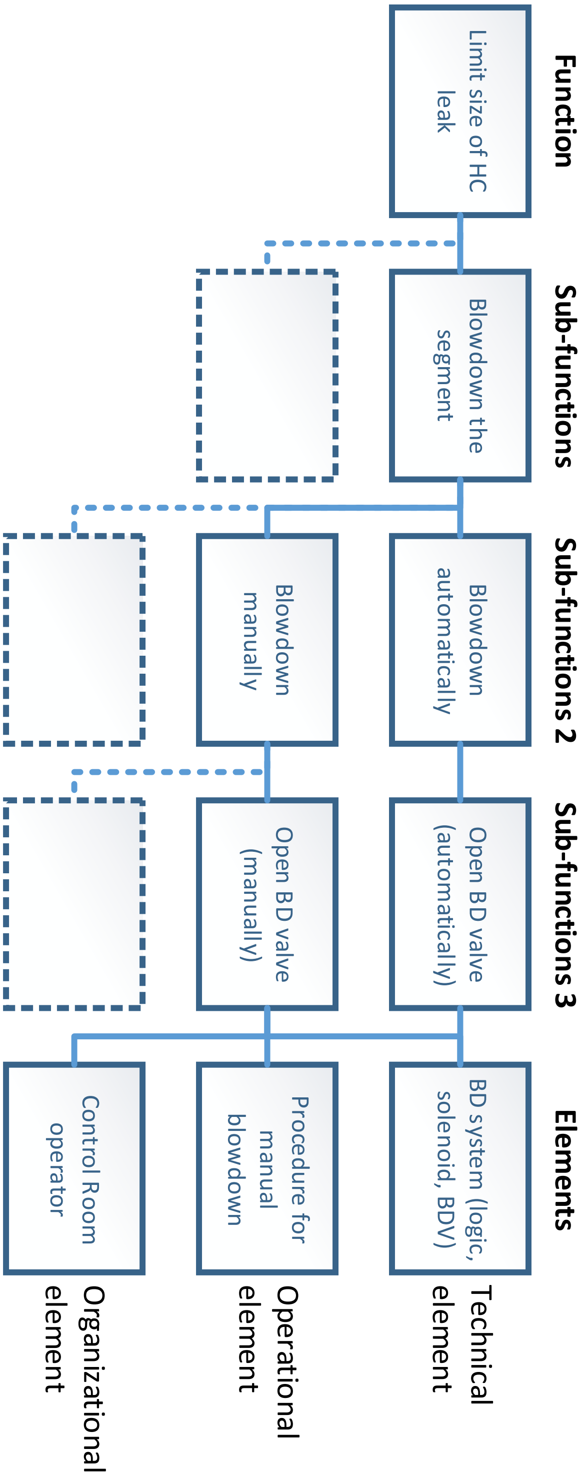

Figure 5. Representative barrier tree (Hansen, 2015).

3.2 *Risk model*

The Risk Barometer application on the FPSO allowed defining a specific risk model, presenting logical relationship between the status of the defined barrier indicators and the area risk level. The available barrier grids (fig. 4) and the related barrier trees (fig. 5) were used as basic structure of the model.

The aggregation rules defining such model are listed in table 1.

Table 1. Risk Barometer aggregation rules defined for this case

Level	Aggregation rule
Barrier grid/ Barrier function	$\prod Freq_{IEV,i} \cdot FProb_{BF,j} = Freq_{Cons}$ Frequencies of initiating events ($Freq_{IEV,i}$) are multiplied by failure probabilities of the related barrier functions ($FProb_{BF,j}$) to evaluate frequencies of consequences.
	$FProb_{BF,j} \propto Deg_{BF,j}$ Direct proportionality with $FProb_{BF,j}$ allows estimating the degradation status (Deg_{BF}).
	$Deg_{BF} = \sum w_{SF,i} \cdot Deg_{SF,i}\ ;\ w_{SF,i} = \frac{1}{N_{SF}}$ Deg_{BF} is evaluated by weighted summation of $Deg_{SF,i}$ (degradation status of sub function). Weights are preliminary defined as uniform.
Sub functions	$Deg_{SF} = \sum w_{El,i} \cdot Deg_{El,i}\ ;\ w_{El,i} = \frac{1}{N_{El}}$ Deg_{SF} is evaluated by weighted summation of $Deg_{El,i}$ (degradation status of Element). Weights are preliminary defined as uniform.
Element	$Deg_{El} = \sum w_{Ind,i} \cdot Ind_i\ ;\ w_{Ind,i} = \frac{1/rank_{Ind,i}}{\sum 1/rank_{Ind,j}}$ Deg_{El} is evaluated by weighted summation of Ind_i (indicator defined for the element). Weights are preliminary defined by means of the related indicator ranking and the Zipf's law (Chen, 2016).
Indicator	$Ind = \mathrm{M}(x)$ Collected indicator measures (x) are defined on a scale from 1 to 6.

Frequencies of initiating events may be retrieved from several data sources (e.g. the "Purple book" by TNO (2005)) and allow defining the baseline for the failure probabilities of the related barrier functions. Moreover, in order to set indicator weights, a preliminary ranking of indicators was defined on the basis of previous related studies (Øien, Utne et al., 2011a, Øien, Utne et al., 2011b):

1. Technical indicators
2. Operational indicators
3. Organizational indicators

3.3 *Simulated results*

Due to scarcity of data, the model was tested on simulated indicator trends in order to evaluate its response. Results of such simulation are reported in figs. 6-7. Both human and environmental risks were assessed and expressed as, respectively, fatalities per year and spill to sea per year.

In particular, figure 6 shows the trend over time of the two risk indexes, which both decrease in the first months of 2016 and variate around an average value in the following months – due to simulated deviations of indicators.

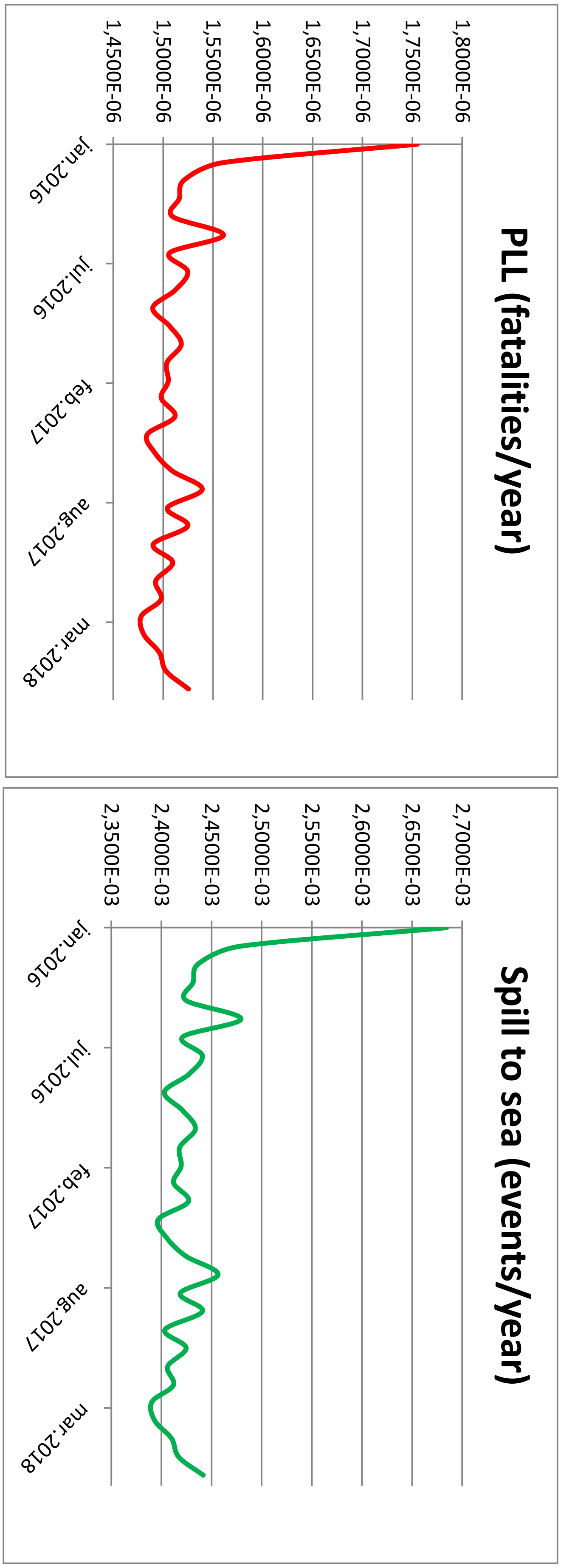

Figure 6. Simulated results from application of the Risk Barometer on this case. PLL=Potential Life Loss

Fig. 7 shows the simulated Risk Barometer indicating the risk level in June 2018 (last value of simulation).

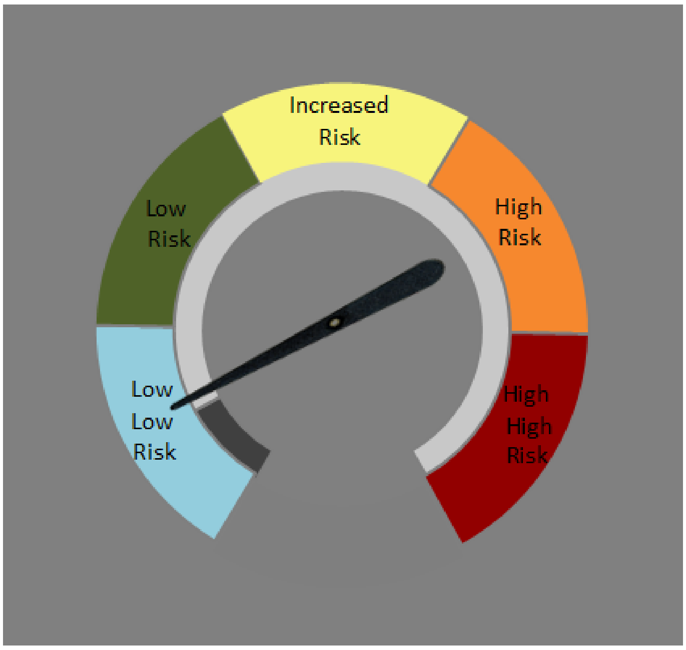

Figure 7. Simulated Risk Barometer for June 2018

4 RISK-RELEVANT KNOWLEDGE FROM RESILIENT FUNCTIONING

Dynamic risk assessment in a scenario with potential for h/d/e risks would allow assessing risk variation due to not only external conditions, but also presumed or observed presence of resilience.
An observation of a successful resilient episode could have various implications for the future, e.g.:

- A presumed positive effect in terms of (anecdotal) evidence of enhanced processes of preclusion, mitigation or recovery.
- A presumed negative effect in terms of amplified damage when eventually failing from higher grounds, risk compensation behavior or higher propensity to seek for borderline conditions.

The scope of assessment is not necessarily on discrete events. It might be asked whether a series of successes has similar effects. Even the opposite (series of failures) may signify a turning point due to accumulated learning.

Grøtan and Paltrinieri (2016) state that resilient episodes cannot be understood out of their context. A model is needed for the safety management process to identify and grasp such occasions. For that purpose, the "drift" model suggested by Snook (2000) may be of inspiration. It might be interpreted further (Grøtan, 2015) to suggest that a drift is not necessarily a "drift into failure", it might as well be a "drift into success" and a manifestation of resilience as a positive outcome of complex system properties

The drift metaphor is recurrent and recursive in the sense that, e.g., technical revisions and redesigns, organizational changes, failures, incidents, accidents, recoveries and not at least mastery of unexpected situations may represent decisive occasions in terms of manifestations, or potential restarts of drift at different scales. A vigilant organization will not "run out of" decisive occasions inviting sense-making work.

The challenge is to derive risk-related knowledge from resilient functioning.

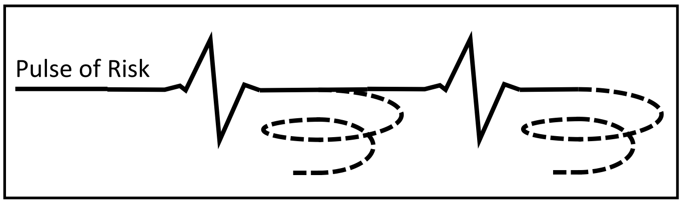

Figure 8. Representation of the Pulse of Risk and following DRMF iteration (fig. 3).

As represented in figure 8, this can be done in a "pulsed" manner (Grøtan, 2015), in which the "pulse beat" is driven by the occasions derived from the drift model. For each pulse beat, there is an expansion phase, a contraction phase, and a succeeding "blood flow" that lasts until the next beat.

- In the expansion phase, the current compliance/resilience reconciliation (Grøtan, 2015) is critically examined.
- In the contraction phase, changes in reconciliations are followed by
    a) a direct revision of existing risk assessments, and
    b) an identification of a need for re-orientation of the "risk horizon".
- In the flow phase, organizational attention is re-organized according to the new risk horizon derived.

This "Pulse of Risk" (PoR) approach (Grøtan, 2015) incorporates and benefits from the DRMF approach represented in figure 3, which is a systematic attempt of reducing uncertainty under specific conditions. The PoR approach can be used to successively re-orient and re-initialize the DRMF process. PoR allows for a shift in the DRMF perspective: from a two-dimension process (fig. 3) designed to continuously integrate exogenous information into risk evaluation, to a three-dimension process (fig. 8) iterated to include also the endogenous conditions provided.

5 CONCLUSIONS

This contribution shows the potential of dynamic risk management when applied to a case of unique safety and environmental features, such as the first oil production platform in the Barents Sea.

Due to lack of knowledge on intertwining between new technologies and environment, the potential for h/d/e risks cannot be excluded. Moreover, continuous performance variability and intrinsic adaptations (resilient functioning) is another potential implication.

In order to deal with system changing conditions, the application of the Risk Barometer technique is suggested. This would allow for real-time monitoring of not only technical performance of barriers, but also the associated operational and organizational systems, with the purpose to evaluate overall risk picture variations.

A generic application example of the Risk Barometer is shown for this case (FPSO in the Barents Sea). Simulation of indicator trends allowed testing the dynamic technique and producing risk variation trends over time.

Risk contribution of both exogenous and endogenous sources can be addressed by this strategy. Under new conditions, organization may also re-orienteer in a “pulsed” manner, triggering iteration of the DRMF approach. DRMF has the potential to update the overall risk picture by deriving risk-relevant knowledge from resilient functioning. For this reason, iteration of the DRMF approach following a “PoR beat” is deemed advisable, in order to shift towards comprehensive safety management and guarantee high levels of protection against environmental damage and harm to humans.

6 REFERENCES

Chen, Y. (2016). The evolution of Zipf’s law indicative of city development. *Physica A: Statistical Mechanics and its Applications* 443 555-567.

Comfort, L. K., A. Boin and C. C. Demchak (2010). *Designing Resilience: Preparing for Extreme Events*: University of Pittsburgh Press.

Grøtan, T. O. (2015). Organizing, thinking and acting resiliently under the imperative of compliance on the potential impact of resilience thinking on safety management and risk consideration. *Production and Quality Engineering*. Trondheim, NTNU.

Grøtan, T. O. and N. Paltrinieri (2016). Dynamic risk management in the perspective of a resilient system. *In* N. Paltrinieri and F. Khan eds. *Dynamic Risk Analysis in the Chemical and Petroleum Industry*. Oxford, United Kingdom, Butterworth-Heinemann.

Hansen, H. N. (2015). Goliat Barrier Management. *Barrierestyring i praksis*. Oslo, ESRA.

Hasle, J. R., U. Kjellén and O. Haugerud (2009). Decision on oil and gas exploration in an Arctic area: Case study from the Norwegian Barents Sea. *Safety Science* 47(6) 832-842.

Hauge, S., et al. (2015). Handbook for monitoring of barrier status and associated risk in the operational phase. SINTEF F27045. Trondheim, Norway Center for Integrated Operations in the Petroleum Industry.

Kyaw, K. and N. Paltrinieri (2015). The cost of reputational damage when a major accident occurs. Safety and Reliability of Complex Engineered Systems - Proceedings of the 25th European Safety and Reliability Conference, ESREL 2015.

Larsen, T., D. Nagoda and J. R. Andersen (2004). *The Barents Sea Ecoregion: A Biodiversity Assessment*: WWF's Barents Sea Ecoregion Programme.

NPD (2015). The Norwegian continental shelf. Oil fields, discoveries, areas awarded and areas that have been opened for exploration activities as of July 10th, 2015. Stavanger, Norway, Norwegian Petroleum Directorate.

Olseon, D. M. and E. Dinerstein (2002). The Global 200: Priority ecoregions for global conservation. *Annals of the Missouri Botanical Garden* 89(2) 199-224.

Paltrinieri, N., et al. (2014). Towards a dynamic risk and barrier assessment in an IO context. Safety, Reliability and Risk Analysis: Beyond the Horizon - Proceedings of the European Safety and Reliability Conference, ESREL 2013.

Paltrinieri, N. and P. Hokstad (2015). Dynamic risk assessment: Development of a basic structure. Safety and Reliability: Methodology and Applications - Proceedings of the European Safety and Reliability Conference, ESREL 2014.

Paltrinieri, N., et al. (2014). Dynamic approach to risk management: Application to the Hoeganaes metal dust accidents. *Process Safety and Environmental Protection* 92(6) 669-679.

PSA (2013). Principles for barrier management in the petroleum industry. Stavanger, Norway, Petroleum Safety Authority Norway.

Snook, S. A. (2000). *Friendly fire : the accidental shootdown of U.S. Black Hawks over Northern Iraq / Scott A. Snook*. Princeton, N.J. ; [Chichester]: Princeton University Press.

TNO (2005). *Guidelines for Quantitative Risk Assessment: Purple Book*. den Hague, The Netherlands: National Institute of Public Health and Environment (RIVM).

Weick, K. (2009). *Making Sense of the Organization: Volume Two: the Impermanent Organization.* Hoboken, New Jersey, US: John Wiley & Sons.

Øien, K., I. B. Utne and I. A. Herrera (2011a). Building Safety indicators: Part 1 – Theoretical foundation. *Safety Science* 49(2) 148-161.

Øien, K., et al. (2011b). Building Safety indicators: Part 2 – Application, practices and results. *Safety Science* 49(2) 162-171.