Improved Safety in the Arctic through Digitalization

Nathaniel John Edwin

Safetec Nordic AS, Norway. E-mail: nathaniel.john.edwin@safetec.no
Health, Safety, Security, Environment and Quality (HSSEQ) Department, Vår Energi, Norway. E-mail: nathanieljohn.edwin@varenergi.no

Live Fornes

Integration & Improvement Department, Vår Energi AS, Norway. E-mail: live.fornes@varenergi.no

Knut Øien

SINTEF Digital, Norway. E-mail: knut.oien@sintef.no

Goliat is an offshore oil field, operated by Vår Energi, in the Norwegian sector of the Barents Sea. The Arctic is considered environmentally sensitive and continued focus on safety is of utmost importance. The Goliat field has implemented a state-of-the-art web-based barrier status panel (BSP) for real-time status monitoring of technical safety-related equipment on the facility. Data is collected from the computerized maintenance management system (CMMS) and the safety and automation system (SAS) to provide operations an in-depth understanding of the risk picture on the facility. Since its roll-out in the summer of 2018, the BSP has been in use offshore, enabling operations to apply a risk-based approach to prioritize and execute maintenance work. This paper presents the BSP as a tool and reflects on the experience and learning gained from first-hand implementation of the same.

Keywords: Barrier, Real-time, Digitalization, Petroleum, Arctic, Safety.

1. Introduction

The Arctic holds close to 22% of the Earth's oil and gas natural resources (EIA, 2009). The Goliat field is the first producing oil field in the Barents Sea. Operated by Vår Energi AS (earlier named Eni Norge) with license partner Equinor, this field has been in production since early 2016. The Arctic is considered environ-mentally sensitive and continued focus on safety during operation is of utmost importance.

One token of the continuous focus on safety is the development of a barrier status panel (BSP). The Goliat Floating Production, Storage and Offloading (FPSO) facility is the first installation on the Norwegian Continental Shelf to leverage the potential of digitalization by including live data from the safety and automation system (SAS) in addition to semi-live data from the CMMS system, to improve safety and risk awareness in operations.

There are no explicit requirements in the Petroleum Safety Authority (PSA) regulations to establish a barrier status panel. On the other hand, the management regulations § 5 states that: *".... Personnel shall be aware of what barriers have been established and which function they are intended to fulfil, as well as what performance requirements have been defined in respect of the concrete technical, operational or organizational barrier elements necessary for the individual barrier to be effective. Personnel shall be aware of which barriers and barrier elements are not functioning or have been impaired. Necessary measures shall be implemented to remedy or compensate for missing or impaired barriers."* (PSA, 2017).

It may therefore be argued that a barrier status panel is a practical way of responding to this PSA paragraph, and in particular the requirement related to knowing which barriers are not functioning or have been impaired. The panel shows status information concerning the barrier elements (degraded or impaired) and it also provides drill down functions to provide the operators with more details about specific barrier elements and how these are related to barrier functions.

The BSP monitors and provides status of 10.600 technical barrier tags (safety-critical equipment) in real time (or close to real time from the CMMS). Focus has been on ensuring that the BSP visualizes the barrier status in a logical and understandable fashion to enable operations to visualize the barrier status and the associated risks while planning, prioritizing and conducting operation and maintenance activities.

This paper describes the development of the tool and the methodology behind the tool (Section 2), and the results in terms of the tool itself and the applications by various user groups (Section 3). The paper also discusses the various successes, drawbacks and pitfalls faced along the way during design, implementation and user training (Section 4).

Proceedings of the 29th European Safety and Reliability Conference.
Edited by Michael Beer and Enrico Zio

Published by Research Publishing, Singapore.
ISBN: 978-981-11-2724-3; doi:10.3850/978-981-11-2724-3_0252-cd

2. Methodology and Tool Development

The development of the barrier status panel – the tool – has included the development and use of several methods and models, starting with the development of a barrier strategy. The roadmap from barrier strategy to barrier status panel is briefly described below. More details for the Goliat case can be found in Nawaz & Jain (2017). General guidance for barrier management in the petroleum industry can be found in Hauge & Øien (2016).

2.1 *Barrier Strategy*

The barrier strategy describes the specific barriers against major hazards/accidents in each area of the installation. The barrier strategy focuses on avoiding or mitigating major accident hazards that are relevant for each main area.

There is a close relationship between the major accident hazards (MAHs) identified and analyzed in the Quantitative Risk Analysis (QRA) and the Defined Situations of Hazard and Accident (DSHAs) with major accident potential identified and analyzed in the Emergency Preparedness Analysis (EPA) and in the Emergency Preparedness Plan (EPP). The DSHA numbers and names from the EPP are used (instead of MAH) in the barrier strategy since the EPP is the most familiar document for the personnel onboard Goliat FPSO.

2.2 *Barrier Functions*

A barrier function is the task or role of a barrier. Barrier functions should mitigate and/or prevent major accident risk at Goliat FPSO.

2.2.1 *Barrier Grids*

The DSHAs occur in a sequence of events, and some of the DSHAs may occur in the same sequence of events. For example, one (*hazard*) DSHA may escalate into an (*accident*) DSHA. In order to stop a sequence of events from developing into an accident, barriers are implemented between the events. Such a sequence of barriers is often referred to as "defense-in-depth", i.e. usually multiple barriers must fail for a major accident to occur.

A barrier grid is a graphical representation used to illustrate the relationship between DSHA's and corresponding barrier functions that prevent and/or mitigate DSHAs within a given area on the installation. Altogether 37 barrier functions have been identified for Goliat FPSO.

2.2.2 *Barrier Trees*

A barrier function may be broken down into several hierarchical levels (sub-functions) to understand the tasks necessary to realize the function. Barrier trees are graphical representations of the barrier functions and underlying sub-functions, developed to facilitate a better overview and understanding.

2.3 *Barrier Elements*

Barrier elements are technical, operational or organizational measures or solutions that play a part in realizing a barrier function.

- Technical barrier elements are equipment and systems playing a part in realizing a barrier function.
- Operational barrier elements are the required description of the actions or activities personnel carry out in order to realize a barrier function.
- Organizational barrier elements are personnel with defined roles or functions to realize a barrier function.

2.3.1 *Barrier Function Performance Standard*

The breakdown of barrier functions into sub-functions and barrier elements are documented as columns in spreadsheets – one spreadsheet for each barrier function (with a mapping towards the relevant main areas).

The spreadsheets contain the bulk of information collected as part of the barrier identification and analysis, including performance requirements and verification activities. The information is imported in an Access database for further import to the barrier status panel.

2.3.2 *Barrier Logic Diagrams (BLDs)*

Barrier logic diagrams (BLDs) are used to verify barrier elements necessary to realize a barrier function. A barrier logic diagram is a simplified visual representation of a barrier function, broken down by sub-functions in the order of which they come into effect, thus the lower part of the BLD represents elements that first come into effect, and the top represents the final realization of the barrier function.

2.4 *Performance Requirements*

Performance requirements are verifiable requirements to control and ensure that the barrier elements perform effectively. This includes safety performance standards (PS) and safety requirement specifications (SRS).

2.5 *Monitoring and Verification*

Three main barrier management activities in operation are:

(i) Safe operation and monitoring of barrier status, including handling of barrier non-conformances (lost or impaired barriers)
(ii) Maintain and ensure the integrity of barriers throughout operation, including verification and evaluation of barrier performance
(iii) Keep the basis for operation of the barriers updated at any time, including the barrier strategy

During operations, we can have both short-term and long-term perspectives for the follow-up of barriers. We may distinguish between 1) information to display the current status of barrier elements, and 2) information to verify the performance requirements.

The first is related to the requirement of being aware of which barriers and barrier elements are not functioning or have been impaired (Management Regulations, Section 5, fifth subsection), i.e. *"Personnel shall be aware of which barriers and barrier elements are not functioning or have been impaired."* PSA (2017).

The second is related to the requirement of being aware of what performance requirements have been defined in respect of the barrier elements (Management Regulations, Section 5, fourth subsection) and to verify these requirements.

Follow-up of barriers in operation includes all activities carried out to maintain the functionality and integrity of the barriers throughout operation, during all operational modes. It includes monitoring of the barrier status, and verification of performance requirements to the barrier elements.

2.6 *Barrier Status Monitoring*

Based on the need for short-term follow-up of the barrier status, and the idea of using live information from the safety and automation system and the CMMS, the layout and content of the BSP was specified. This included which indicators or signals of impairment to capture from which data systems, and rules for aggregation of impairments to e.g. system, function and area level. The result is presented in the next section.

3. Results

3.1 *The Barrier Status Panel (BSP)*

The Goliat BSP was developed with the objective to provide operations with an accurate and real-time status of all technical barrier elements on the Goliat asset, thereby providing decision-input to work prioritization and execution. Figure 1 shows an overview of the aggregated status on area level, which is part of the entry page.

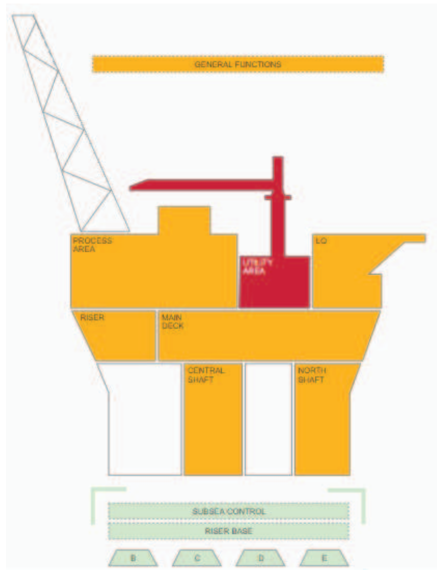

Fig. 1. Overview figure on entry page showing barrier status on each of the main areas on Goliat (only test data)

The barrier status is indicated using color coding depending on the number and criticality of impaired barrier tags (B-tags) affecting the area, and the status on handling the impairments. This is explained below.

3.1.1 *Impairment Signals and Tag Status*

The impairment signals taken from the CMMS and SAS, and basic rules are defined to assign the tag status as red, yellow or green.

Examples of impairments for the various signals are:

- Safety Faults: Valve does not close within required time constraints (Red)
- Condition Monitoring Signals: Dirty optics on gas detector (Yellow)
- Inhibits SAS: High-high trip on pressure transmitter is disengaged (Red)
- Corrective Maintenance: Actuator on valve is broken (Red/Yellow)
- Overdue Preventive Maintenance: Stroke test of valve is delayed (Red/Yellow)

3.1.2 *Tag Status after Handling*

Impaired tags shall be handled (risk evaluated and possibly compensated). The tag handling status is presented in the BSP using special symbols, and in some cases, credits are given for the handling such that the color is reduced from red to yellow/green or yellow to green.

The following may apply for an impaired tag: Not yet risk evaluated (NONE), risk evaluated but not compensated (RISK), compensated (COMP), considered not to represent a risk (NORI), or the risk may be invalidly evaluated (INVALID). A tag may also be temporarily disabled (DISREG), or the tag may be healthy (green status). This is shown in Figure 2, including the symbols used before and after handling is performed.

Status/ code	Description	Tag status before handling	Tag status after handling
NONE	Impairment is not handled		-
			-
RISK	Function of barrier is impaired, but no compensating measures are implemented		
COMP	Technical, operational or organisational measures are incorporated to compensate for the impairment		
NORI	Impairment does not affect the barrier function, or the risk increase is considered insignificant		
INVALID	Incorrect or conflicting risk assessment is registered on the tag		
DISREG	Tag is temporarily disabled		-
-	Tag is healthy – no impairments registered		-

Fig. 2. Tag handling status, status code, and symbols applied in the BSP

Example of risk evaluation of level transmitter in a critical tank that is not functioning:

- RISK: Uncertainty in level measurement – no alternative means to determine the level
- COMP: Gauge glass on the tank is used manually to measure the level
- NORI: Tank is currently out-of-service; thus, impairment does not affect risk

The overall handling status is displayed on the entry page in the BSP, as shown in Figure 3.

HANDLING STATUS

INVALID	NONE	RISK	COMP	NORI
2	1	2	110	4
0	5	4	7	48

Fig. 3. Tag handling status in the BSP (only test data)

3.1.3 *Tag Criticality Assessment*

The importance of an impairment is not only dependent on the tag status in terms of color (red, yellow, or green) after handling; it is also dependent on the criticality of the tag (the equipment). The tag status (color) is combined with the criticality to obtain a score. This constitutes a risk-based approach to assign the importance of an impairment and the aggregation of impairments on higher levels (e.g. system, function and area).

Each tag (equipment) that is classified as a barrier element is criticality assessed on a scale from 1-6. Criticality is defined as a function of "risk reduction" and "redundancy". High risk-reduction and low-redundancy implies high criticality (6). Tags such as fire doors, blast doors/walls, critical isolation valves etc. are given criticality 5 or 6. Tags with high-redundancy, low risk-reduction are given a low criticality (1). Examples of this include emergency lighting, PA/GA equipment etc. The criticality assessment allows us to differentiate between high-criticality barrier impairments vs. low-criticality barrier impairments. Figure 4 shows the adopted criticality matrix.

Redundancy	Consequence/risk reduction			
	0 (Minor)	1 (Severe)	2 (Major)	3 (Extensive)
A (no redundancy)	3	4	5	6
B (one failure "allowed")	2	3	4	5
C (≥ two failures "allowed")	1	2	3	4

Fig. 4. Criticality matrix

Details about the criticality assessment can be found in Hoem et al. (2016).

The obtained tag score based on the tag status and tag criticality. E.g. Tag Status =Red and Tag Criticality =6 will give a high tag score =32.

Tag Status = Red and Tag Criticality=2 will give a lower tag score of 2. This provides a risk-based scoring of tag impairments.

3.1.4 *Aggregation Rules*

When the status of each tag is known, this information can be used to present aggregated status on systems, performance standards and areas, as well as the levels between tags and area. This is done by summarizing the scores on all impaired B-tags belonging to the different levels, which then is compared to predefined threshold values corresponding to red, yellow or green status on the aggregated levels.

These aggregated statuses are used as "warning signals", i.e. if the aggregated status is yellow or red, then some of the underlying tags are impaired (yellow or red) and needs to be looked further into by applying drill-down. When a system, PS, and/or area becomes yellow or red, or has stayed this way for a defined time period, this will trigger a certain response, i.e. they are "triggering events".

3.1.5 *Visualization of Barrier Status*

The BSP has many different menus, including an entry page, three main views (area, system and performance standard), and a work planning menu. Figures 1 is an example of visualizations included on the entry page.

The area view includes e.g. visualizations presented in Figures 5 and 6.

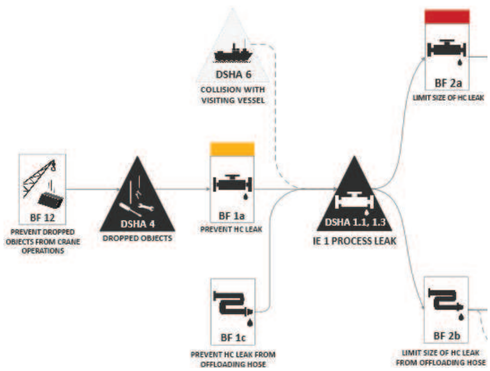

Fig. 5. Left part of barrier grid for process area (only test data)

The barrier grid (cf. Section 2.2.1) illustrates barrier functions (rectangles) to prevent or mitigate DSHAs (triangles). The status of barrier function (BF) 1a is yellow, whereas the status of BF 2a is red, i.e. some underlying tags are impaired. Mouseover provides more information.

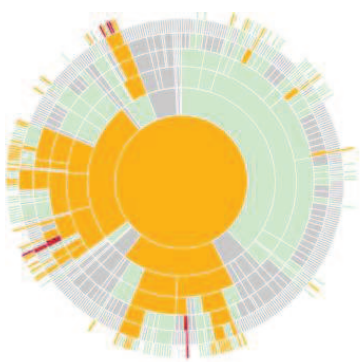

Fig. 6. Sunburst for process area (only test data)

The sunburst visualizes the impaired tags (outer circle) and how the status propagates via the various barrier function levels towards the center, which is the area level.

3.2 *Applications by Various User Groups*

3.2.1 *Application in Normal Workflow*

The workflow from an impaired barrier tag is discovered until it is fixed is illustrated in Figure 7.

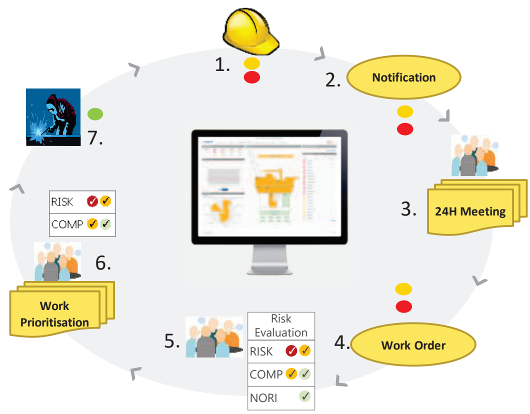

Fig. 7. Workflow of handling impaired barrier tags

First, starting from the top, an operator discovers an impairment in the field; this could be during preventive maintenance such as functional testing. Impairments can also be discovered by the Central Control Room (CCR) operator through alarms from the Safety and Automation System (SAS).

Second, after an immediate first-line evaluation of the criticality of impairment, a notification is written in the CMMS. Approved notifications on barrier tags will show in the BSP.

Third, the "24-hour meeting", which is onshore, reviews all the notifications. System and discipline engineers are involved if requested. The BSP is used prior to this meeting to identify the criticality of barrier impairments.

Fourth, the work orders are created in the CMMS.

Fifth, the system engineers carry out the risk evaluations of the impairment and the outcome of the evaluations are entered directly in the work order in the CMMS. The result of the risk evaluation and handling is described in Section 3.1.2, and the presentation in the BSP is shown in Figure 3.

Sixth, the BSP is used actively to identify which work orders that need to be carried out first in order to reduce risk, and the BSP is used by work planners in work planning meetings (daily WP meetings, 24-hour meetings, weekly planning meetings and 14-day plan meetings).

Seventh, based on the risk evaluations and the subsequent prioritization of the work orders, the impairments are fixed in a prioritized order. The tag then is green, i.e. functioning.

As stated above, system and discipline engineers, and work planners, actively use the BSP. In addition, management use the BSP to get an overview of the barrier and risk status on Goliat FPSO. Relevant visualizations in the BSP are briefly described below.

3.2.2 *Application by Management*

Aggregated area status and performance status (using e.g. Figures 1) are evaluated by management on a daily, weekly and monthly basis – and are important input to integrated risk management for the Goliat FPSO. Through the BSP the organization gets real-time status and all the data about the tags are available. However, the data must be interpreted in order to make informed decisions. This can still be a challenge, and a prerequisite to make it work is thorough training of involved personnel in addition to commitment and awareness by the managers.

3.2.3 *Application by System Responsible*

The red and yellow lights at an aggregated level in the BSP, e.g. system level, are only "warning signals" that indicate that further evaluation/ action is needed (cf. Section 3.1.4). The BSP will not give you all the answers; personnel need to evaluate and analyze the information that the BSP give and act accordingly. For this we use trigger events (cf. Section 3.1.4).

One of the main views in the BSP is the system view adapted to the system responsible. For example, if a system has been red for more than 4 weeks, the system owner must evaluate the status of the system based on the information in the BSP (considering which tags are contributing to the 'redness', which are the most critical and which actions are needed). These evaluations shall be documented.

3.2.4 *Application by Work Planners*

There is a dedicated work planning menu for work planners in the BSP. It includes an overview table of all impairments with shortcuts and search opportunities (filters), various KPIs, overview of work orders, and trend curves for impairments in various handling statuses, i.e. NONE, RISK, COMP and NORI.

4. Discussion

4.1 *Comparison with Other Solutions*

Edwin (2015) provides a taxonomy of methods/ approaches for operational risk analyses adopted in the oil and gas industry. Most oil and gas operators today use "status and monitoring" solutions that promote integrated management of safety critical information (status of barriers, deviations, ongoing activities, etc.) through better visualization and or data management and reporting. Real-time barrier status monitoring is a reality today due to the advent of digital technology across the industry.

Some examples of other barrier or risk status monitoring solutions in the industry include – Total Risk by Shell (Schellings, 2013), Cumulative Risk Assessment by British Gas (Cassidy, 2011), and TIMP by Equinor (earlier Statoil) (Refsdal & Urdahl, 2014) to name a few. A common denominator between these solutions is their dependence on qualitative data or user-based evaluations, which makes them labor-intensive. The iSee system developed by ConocoPhillips (Etterlid, 2013) is an exception wherein data from the maintenance management system is overlaid on plot plans for the facility. This allows users to visualize interdependencies between work tasks and thereby plan safer and more efficiently.

Some of the other solutions, e.g. TIMP, do not provide real-time data, and those who do, usually only apply data from the CMMS. The Goliat BSP solution takes this one step further by also integrating real-time data from the SAS along with information from the CMMS, including planned maintenance.

4.2 *Successes*

One of the major factors towards the successful launch of the tool was the end-user involvement during the development phase. Allowing the users to influence the development, provide their feedback and input to the tool is paramount in ensuring that the tool provides what the users need. This also allowed us to clearly map user-requirements in a systematic fashion, and provided a corrective loop allowing for minor changes along the way.

The tool today is used actively on a day-to-day basis, both onshore and offshore. The tool allows for better cooperation and communication between land and offshore, enabling for risk-based prioritization and execution of maintenance. Finally, and most importantly, the tool has improved barrier and risk awareness in operations, thereby creating engagement and dialog on the same. This thereby is an important contributor to safe operations.

4.3 *Learnings*

Both engineering and development takes time. It is important to keep this in mind and provide realistic milestones, both to the project but also to end-users.

Adoption of a new system and tool does not happen overnight. User training and front-line support were underestimated by the project. This is something that needs to be well thought of, planned for and executed to ensure that the users are ready when the tool is released.

Developing a comprehensive and rather detailed program specification is important to avoid delays and cost changes during software development. One way to mitigate this is to allow discipline relevant personnel to work closely with the software developers to ensure that the specification is correctly understood.

Management involvement is very important. Without backing from relevant management, ownership will be lacking. Management should actively inquire about the tool and prompt their staff to use the tool more actively.

4.4 *Way Forward*

The barrier status panel in its current form monitors the real-time status of technical barriers. While this is satisfactory, several upgrades are planned for the near future – both to fix known gaps, but also improve the coverage of the tool – to represent an as accurate risk-picture as possible.

4.4.1 *Other Risks or Non-Conformities*

Real-time information from the maintenance system (CMMS) and the safety and automation (SAS) system are limited. In operations, there are also other systematic failures, deviations or non-conformities that cannot be linked to a specific tag/equipment in the maintenance system and is therefore logged in another software tool for risk management, e.g. Synergi Life – QHSE and enterprise risk management software (2019). For instance, this could include known weaknesses in reliability of a given set of equipment, an HSE incident concerning a specific location on the installation etc. Such aspects are not logged in the maintenance management system, but in this secondary tool for enterprise risk management (Synergi).

The project plans to open for integration with this software, to allow users to import cases that are relevant for barrier performance to the barrier panel. This will allow for the barrier status panel to be more comprehensive and include other relevant barrier weaknesses than those automatically logged in the real-time systems.

4.4.2 *Operational and Organizational Barriers*

Various studies, accident investigations etc. have time and time again shown that management of human factors are key in ensuring safe operations. e.g. Vinnem (2013, 2015). Therefore, the Petroleum Safety Authority in Norway place strong focus on operational and organizational barriers and their integration with technical barriers.

In order to improve control and awareness of the same, the barrier project plans to integrate the status monitoring of operational and organizational barriers into the BSP. This involves identifying all relevant safety-critical-tasks for the facility and personnel involved in the same, i.e. "*Who does what in which situation?*". The barrier panel shall then monitor competence fulfilment of the relevant personnel and indicate if a given safety-critical-task lacks either personnel available on-board or if relevant personnel have missing or outdated competence to perform their tasks. Preliminary work on this is presented in Kilskar et al. (2016).

4.4.3 *Work Permit Systems*

In order to ensure the usefulness of barrier status monitoring solutions in a work approval context, barrier status information must be integrated within the work planning environment, i.e. computerized maintenance management systems. The way forward is therefore to present barrier status information along with information on planned work so that decisions are made with the right contextual information. Oil and gas operators such as ConocoPhillips (Etterlid, 2013) and Equinor (2019) already overlay work planning information over 2D plot plans of the facility in their permit-to-work systems. The next step forward is to include barrier status information along with this.

5. Acknowledgement

We would like to acknowledge the valuable contribution from Safetec and SINTEF during the engineering and development phase of the barrier management project, and Eigen Ltd. who provided the technical platform and software design for the barrier status panel. Thanks are also given to Equinor as licensee in PL229 (Goliat Field).

We also express a special thank you to Stein Tyldum (ICT project leader) from the ICT Department in Vår Energi, and to the members of the user reference group (i.e. the key users) and to various people within the Technical Integrity Departments, the ICT Department and Operation Departments (onshore and offshore) who made the BSP a reality.

6. References

Cassidy, K. (2011). The Cumulative Risk Assessment Barrier Model. https://www.onepetro.org/conference-paper/SPE-146255-MS. (Accessed: 22-Feb-2019).

DNV-GL (2019). QHSE and risk management software | Synergi Life. https://www.dnvgl.com/services/qhse-and-enterprise-risk-management-software-synergi-life-1240. (Accessed: 23-Feb-2019).

Edwin, N.J. (2015). Activity-based Modelling for Operational Decision-support (Master's Thesis, NTNU)

Etterlid, D. (2013). iSee Visualising Risk-based Data. http://www.ptil.no/getfile.php/1325159/PDF/Seminar%202013/Integrerte%20operasjoner/iSee_visualisering%20av%20risikorelaterte%20data.pdf. (Accessed: 22-Feb-2019).

Equinor (2019). Equinor and eVision - a global partnership in Permit to Work innovation, eVision Software. https://www.evision-software.com/project/statoil/. (Accessed: 23-Feb-2019).

EIA (2009). Arctic Oil and Natural Gas Potential; US Energy Information and Administration https://www.eia.gov/analysis/studies/archive/2009/arctic/index.html. (Accessed: 03-Mar-2019)

Hauge, S. and K. Øien (2016). Guidance for barrier management in the petroleum industry, SINTEF F27608.

Hoem, Å.S., K. Øien, S. Hauge, and L. Bodsberg (2016). Aggregation and presentation of safety barrier status information. The European Safety and Reliability Conference (ESREL 2016), 25-29 September 2016, Glasgow, Scotland.

Kilskar, S.S., K. Øien, S. Hauge, Å.S. Hoem, and L. Bodsberg (2016). Monitoring of operational and organizational safety barriers. The European Safety and Reliability Conference (ESREL 2016), 25-29 September 2016, Glasgow, Scotland.

Nawaz, Z. and P. Jain (2017). Barrier Status Panel - Tool for Barrier Management. Int. Conf. Syst. Reliab. Saf., 2017.

PSA Norway (2017). The Management Regulations; 18 December 2017.

Refsdal, I. and O. Urdahl (2014). Technical Integrity Management in Statoil. Abu Dhabi International Petroleum Exhibition and Conference, 2014.

Schellings, D. (2013). Total risk approach. SPE Offshore Europe Oil and Gas Conference and Exhibition, 2013.

Vinnem, J.E. (2013). On the development of failure models for hydrocarbon leaks during maintenance work in process plants on offshore petroleum installations. *Reliab. Eng. Syst. Saf.*, vol. 113, pp. 112–121, May 2013.

Vinnem, J.E. (2015). Analysis of hydrocarbon leaks and verification as an operational barrier. *J. Risk Res.*, vol. 18, no. 9, pp. 1130–1144, Oct. 2015.