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**REAL-TIME DATA FOR RISK ASSESSMENT IN THE OFFSHORE OIL&GAS
INDUSTRY**

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ABSTRACT

Recent major accidents in the offshore oil and gas (O&G) industry have showed inadequate assessment of system risk and demonstrated the need to improve risk analysis. While direct causes often differ, the failure to update risk evaluation on the basis of system changes/modifications has been a recurring problem. Risk is traditionally defined as a measure of the accident likelihood and the magnitude of loss, usually assessed as damage to people, to the environment, and/or economic loss. Recent revisions of such definition include also aspects of uncertainty. However, Quantitative Risk Assessment (QRA) in the offshore O&G industry is based on consolidated procedures and methods, where periodic evaluation and update of risk is not commonly carried out. Several methodologies were recently developed for dynamic risk analysis of the offshore O&G industry. Dynamic fault trees, Markov chain models for the life-cycle analysis, and Weibull failure analysis may be used for dynamic frequency evaluation and risk assessment update. Moreover, dynamic risk assessment methods were developed in order to evaluate the risk by updating initial failure probabilities of events (causes) and safety barriers as new information are made available. However, the mentioned techniques are not widely applied in the common O&G offshore practice due to several reasons, among which their complexity has a primary role. More intuitive approaches focusing on a selected number

of critical factors have also been suggested, such as the Risk Barometer or the TEC2O. Such techniques are based on the evaluation of technical, operational and organizational factors. The methodology allows supporting periodic update of QRA by collecting and aggregating a set of indicators. However, their effectiveness relies on continuous monitoring activity and real-time data capturing. For this reason, this contribution focuses on the coupling of such methods with sensors of different nature located in or around and offshore O&G system. The inheritance from the Centre for Integrated Operations in the Petroleum Industries represents the basis of such study. Such approach may be beneficial for several cases in which (quasi) real-time risk evaluation may support critical operations. Two representative cases have been described: i) erosion and corrosion issues due to sand production; and ii) oil production in environmental sensitive areas. In both the cases, dynamic risk analysis may employ real-time data provided by sand, corrosion and leak detectors. A simulation of dynamic risk analysis has demonstrated how the variation of such data can affect the overall risk picture. In fact, this risk assessment approach has not only the capability to continuously iterate and outline improved system risk pictures, but it can also compare its results with sensor-measured data and allow for calibration. This can potentially guarantee progressive improvement of the method reliability for appropriate support to safety-critical decisions.

INTRODUCTION

Major accidents in various industrial sectors have showed inadequate assessment of system risk and demonstrated the need to improve risk analysis. For instance, Nelson and Green [1] have highlighted the lack of awareness on the conditions of safety measures (aimed to mitigate risk) in infamous accidents of the nuclear and space industries – respectively the Three Mile Island accident and the space shuttle Columbia disaster.

The offshore oil and gas (O&G) industry is not exempt from such deficiencies. A series of serious accidents both in Norway and worldwide were witnessed in the last years. The blowouts at Snorre Alpha in 2004 [2], Montara in 2009 [3], Macondo in 2010 [4] and the loss of well control at Gullfaks C in 2010 [5] are some of the most representative examples.

Direct causes of such events often differed, but a number of underlying causes were identified as recurring problems by Timmannsvik et al. [6]. In particular, one of the most important issue was the failure to update risk evaluation on the basis of system changes/modifications.

Risk is traditionally defined as a measure of the accident likelihood and the magnitude of loss [7], usually assessed as damage to people, to the environment, and/or economic loss [8]. Recent revisions of such definition include also aspects of uncertainty [9]. However, Quantitative Risk Assessment (QRA) in the offshore O&G industry is based on consolidated procedures and methods [7,10,11].

The accidents mentioned highlight the need for improved tools for risk estimation and evaluation. Periodic evaluation and update of risk is not commonly carried out. This leads to static risk estimation in a frozen instant of the system life, without capturing the variation of risks due to operation or changes during the lifecycle of a production plant [12–14].

International standards (e.g. ISO 31000 on risk management [7] and NORSOK z-013 on risk and emergency preparedness analysis [15]) suggest updates of risk analysis in conjunction with major changes in the plant or organization or every five years. Falck et al. [16] share such concern and affirm that risk assessment performed for the design phase of a plant is not suitable for the following phases.

Dynamic fault trees [17], Markov chain models for the life-cycle analysis [18], and Weibull failure analysis [19] may be used for dynamic frequency evaluation and risk assessment update. Moreover, dynamic risk assessment methods were developed in order to evaluate the risk by updating initial failure probabilities of events (causes) and safety barriers as new information are made available during a specific operation [20]. However, the mentioned techniques are not widely applied in the common O&G offshore practice due to several reasons, among which their complexity has a primary role.

More intuitive approaches for frequency modification may focus on a selected number of critical factors, in order to achieve a potential cost-effective solution. Frequency modification factors address site-specific elements related to the facility under review [13,21] and may be updated in (quasi) real-time. The Risk Barometer is a representative example of such approach [22–24].

Its limitations are mainly related to the arbitrariness used for its setting, which represent an obstacle to application and use in new cases.

A step forward was attempted by Landucci and Paltrinieri [25] with a novel method focusing on time-varying frequency modification factors able to link the equipment and management features of the facility to accident frequency values. The methodology (named TEC2O) is based on the evaluation of technical, operational and organizational factors, implicitly considering the role of human factors in the failure frequency. The methodology allows supporting periodic update of QRA by collecting and aggregating a set of indicators, which are defined in agreement with the company owning the facility.

However, effectiveness of dynamic risk assessment methods relies on continuous monitoring activity and real-time data capturing. It implies the necessity to collect early warnings, near misses, incidents, accident data, and indicators. Possible difficulties in gathering field data strongly affect frequency modification methods for QRA update. For this reason, this contribution focuses on the coupling of such methods with sensors of different nature located in or around and offshore O&G system. The inheritance from the Centre for Integrated Operations in the Petroleum Industries represents the basis of such study. Examples of real-time data collection and process will be presented by means of representative simulations of dynamic risk assessment. This will demonstrate how critical offshore O&G cases may benefit from such dynamic approach.

INHERITANCE FROM THE CENTRE FOR INTEGRATE OPERATIONS IN THE PETROLEUM INDUSTRIES

The field of Integrated Operations (IO), whose importance has rapidly grown in the petroleum industry, can represent a response to risk assessment challenges. IO is being developed not only to improve capture of real-time data, but also to process, visualize and share this information for closer onshore-offshore collaboration and more effective expert support. IO concerns the integration of people, work processes and technology and Lil-leng and Sagatun [26] affirm that seven interdependent conditions need to be in place to create value from it:

- New technology enabling new methods of data capture that were previously too costly and risky.
- Increased capacity in the communication infrastructure, e.g. via fiber-optics, to handle accelerated data capture across geographically distributed actors.
- Integration and processing of data from various sources that makes information easy to access by users across disciplines and companies.
- Presentation and visualization of information for everyone who needs it in a user-friendly manner.
- Interdisciplinary collaboration work arenas where team members can connect to other members and have access to information, e.g. collaboration rooms for various offshore as well as onshore units.
- New ways of organizing work processes based on information distribution and collaboration arenas that a) integrate operators, contractors and service companies

more closely; b) integrate onshore and offshore organizations; and c) establish expert support. Work is distributed across geographical, organizational and disciplinary borders.

- An IO mindset among staff that enhances the possibilities provided by technology, e.g. trust and openness to knowledge sharing, interdisciplinary collaboration and focus on continuous change management.

IOs have the potential to support decision-makers of the offshore O&G industry in a smarter way by means of the listed capabilities – summarized and illustrated by figure 1.

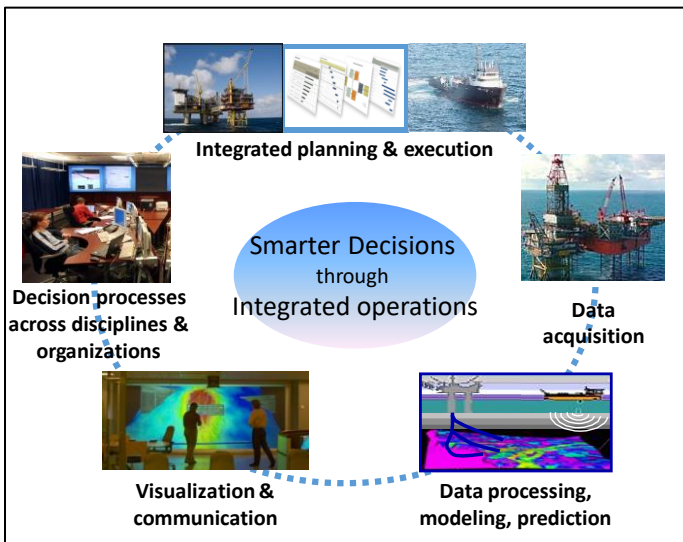


Figure 1. Capabilities of Integrated Operations

For this reasons, the Centre for Integrated Operations in the Petroleum Industry was established in Norway with the support from the Norwegian Research Council and sponsorship from major international oil companies and suppliers and 3 research institutions. The IO Centre is a research-based innovation centre that aims to develop new methods and tools for the integration of people, organizations, work processes and disciplines through new information and communication technology. For instance, IOs are being developed to improve capture of real-time safety data and to process, visualize and share this information for closer onshore-offshore collaboration and more effective expert support [22].

IOs represent the foundations of a series of studies addressing the performance of safety barriers (passive or active, physical, technical, or human/operational systems aiming to prevent, control, or mitigate undesired events or accidents [27]) and how it affects the overall risk picture. Another aim of such studies is the development of techniques that are capable to visualize risk changes and provide important decision support not only during daily operations but also on the medium term. For example, they would allow defining a maintenance plan by assessing the effect of safety barrier impairment on the overall risk.

Some examples are the Technical Integrity Management Programme (TIMP) by Statoil [28], iSee by ConocoPhillips [29], and the Barrier Panel by ENI Norge [30], which focus on measuring the integrity of the technical barriers, but do not explicitly relate it to the overall risk. Another representative example is the previously mentioned “Risk Barometer”, which was developed within the IO Centre. This tool is influenced by previous analogous methods, such as the ORIM (Organizational Risk Influence Model) [31] and Risk OMT (risk modelling – integration of organisational, human and technical factors) [32].

REPRESENTATIVE CASES BENEFITING FROM DYNAMIC RISK ANALYSIS

Several situations within the offshore O&G industry may benefit from dynamic risk analysis. This contribution addresses two cases that are considered representative because of the presence of specific sensors providing real-time data and the popularity gained through public debates.

Oil platforms with high sand production

During oil extraction from a subsea well, sand may be produced. Sand formation may lead to potential erosion and corrosion of oil pipelines. For this reason, several typologies of safety barriers may be employed, as shown by Paltrinieri et al. [33].

One of the main causes of pipeline material degradation involves excessive sand production rate, i.e. increase in both sand production and flow velocity, exceeding a critical threshold. The two safety barriers in place to prevent sand erosion are:

- Gravel pack
- Sand response procedure

A gravel pack is a downhole filter, which is held in place with a properly-sized screen. In case the gravel pack is not enough, and excessive sand production is detected, a specific sand response procedure should be carried out.

The use of sand detectors allows assessing the extent of the cause (sand production rate), but may also be considered as technical components of the sand response procedure barrier. Paltrinieri et al. [33] has identified two means for detecting sand production:

1. Acoustic Sand Detector (ASD) that performs on line monitoring and gives immediate information. It records the noise produced by sand carried in the process flow. The detectors are placed on the outside of the flow line bends and detect the noise made when sand collides with the pipeline wall.
2. Erosion probe, i.e. a metallic surface inserted in the well stream which is physically eroded by sand particles passing. This detector only reports accumulated effects over a longer time period.

The sand response procedure implies that if sand is detected and its rate exceeds a specific threshold, the flow line should be choked back until the sand production rate is acceptable. Generally, the acoustic sand detector is used for dynamic

monitoring and the erosion probe represents a later confirmation of the result obtained.

Corrosive environment and sand under deposit may be another cause of pipeline material degradation – in this case corrosion. The gravel pack is again indicated by Paltrinieri et al. [33] as safety barrier because it can prevent sand production and sand deposit where the flow is slowed down by line bends. Injection of appropriate chemicals into the fluids in order to inhibit corrosion (chemical treatment) is another safety barrier defined to prevent corrosive environment, which is itself composed by technical and operational measures, such as the equipment used and its management. Moreover, "Pigs" are devices that are placed inside the pipe and traverse the pipeline. Thus, pigging is considered as safety barrier because it allows cleaning the pipeline from sand deposit.

As shown by Mayer-Schönberger and Cukier [34], oil corrosiveness (extent of the cause) can be monitored through multiple wireless sensors measuring level stress on pipes, whose main role is to monitor stress corrosion cracking.

Other safety barriers can be employed to mitigate material degradation [33]. Erosion corrosion allowance may be considered present for the pipeline wall thickness. Operational strategy is also a safety barrier. In fact, change of strategy when a critical situation is acknowledged can be the last option in order to prevent loss of production or loss of containment. For instance, in a condition of highly degraded material, production strategy can be modified and the production rate decreased, in order to reduce the pipeline stress load and avoid the formation of a leak of hydrocarbon into the sea.

Oil platforms in environmentally sensitive areas

The recent proposal of installing offshore oil platforms in environmentally sensitive areas, such as the Arctic, have raised general concern within the society. For instance, the Barents Sea is an area with increasing maritime activity and scarce onshore infrastructure. The recent installation of a Floating Production Storage and Off-loading units (FPSOs) in this region [35] may hide the emergence of unexpected risks due to the intertwining of new technologies and fragile environment.

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 [36]. The ecoregion supports abundant fish stocks as well as high concentration of nesting seabirds and a diverse community of sea mammals [37].

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 [37]:

- Naturalness;
- Representativeness;
- High biological diversity;
- High productivity;

- Ecological significance for species;
- Source area for essential ecological processes or life-support systems;
- Uniqueness; and
- Sensitivity.

Hasle et al. [38] 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. These events may lead to consequences for the environment and subsistence of economy activities. Moreover, they may represent important economic and reputation losses [39], 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 may lead to emerging risks, because 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.

A FPSO unit in an environmentally sensitive area should ensure safe and reliable production with the least environmental impact. The FPSO in the Barents Sea taken as example [35] has on board fully processing facilities, with stabilized crude oil stored in the cargo tanks. This is directly offloaded from the FPSO to shuttle tankers through an offloading system. Despite it is not explicitly mentioned for this platform, FPSO may use acoustic multibeam sonars for detection of leakage from subsea infra structures, hydro carbonate suspended in the water, under ice or on the sea bed. In fact, Eriksen [40] states that such sonars have achieved a major breakthrough in terms of performance, physical size, power consumption, uplink flexibility, processing, and price.

SENSOR-BASED RISK ANALYSIS

Risk analysis based on real-time data needs both an appropriate framework for dynamic evaluation and reliable equipment for data collection [41].

Dynamic risk analysis

A bow-tie diagram was used to visualize a generic scenario addressing both the cases of sand production and environmentally sensitive area of oil production (figure 2). The bow-tie technique in its visual form makes an accident scenario easy to understand, and can show what safeguards protect against particular initiating causes (blue boxes in figure 2) and loss event consequences (red box in figure 2) [42].

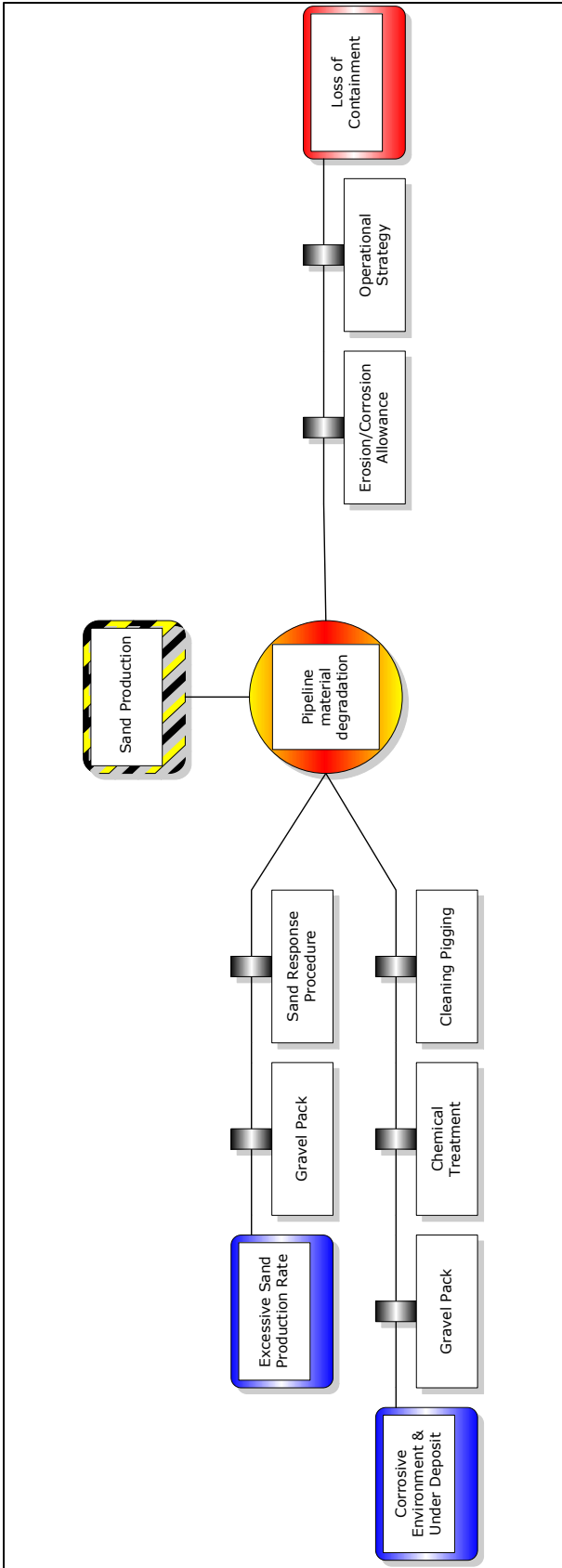


Figure 2. Bow-tie diagram defined by means of BowTieXP®

Table 1. Definition of model elements

Model elements	Definition
<i>Causes</i>	<p>The cause status is defined by a set of indicators.</p> <p>The indicators ($x_{T,i}$) are measured on an arbitrary scale and translated into 1-6 marks.</p> $m_{T,i} = M(x_{T,i})$ <p>A weight ($w_{T,i}$) is assigned to each indicator and the cause status (T) is obtained by a weighted sum on a 1-6 scale.</p> $T = \sum w_{T,i} m_{T,i}$
<i>Barriers</i>	<p>The barrier performance is defined by the performance of the barrier measures, which in turn are defined by indicators.</p> <p>The indicators of each measure ($x_{B,MP,i}$) are measured on an arbitrary scale and translated into 1-6 marks.</p> $m_{B,MP,i} = M(x_{B,MP,i})$ <p>A weight ($w_{B,MP,i}$) is assigned to each indicator i, and a measure of performance j (MP_j) is obtained by a weighted sum on a 1-6 scale.</p> $MP_j = \sum w_{B,MP,i} m_{B,MP,i}$ <p>A weight ($w_{B,j}$) is assigned to each barrier measure j and the overall barrier performance (B) is obtained by a weighted sum on a 1-6 scale.</p> $B = \sum w_{B,j} MP_j$ <p>The barrier performance is translated into a probability of failure (p).</p> $p = P(B)$
<i>Top event</i>	<p>The state of the top event (E) is obtained by summing the contributions from the branches.</p> $E = T_1 p_{T1} + T_2 p_{T2} w_T + T_3 p_{T3} (1 - w_T)$
<i>Consequence</i>	<p>The consequence risk (C) is obtained by the multiplication of E and the failure probability of mitigation barriers p_C.</p> $C = E p_C$

In this case, the causes are: i) excessive sand production rate; ii) corrosive environment & under deposit of sand. The top event is material degradation due to sand erosion/corrosion. The identified consequence is loss of containment. Between causes, top event and consequences, safety barriers are implemented in order to stop the development of the scenario by either preventing or mitigating the events considered.

The Bow-Tie diagram allowed defining a semi-quantitative model for risk assessment, combining both the assessment of the related causes and the performance of barriers employed. The risk of loss containment is dependent on both the status of the causes and the performance of the barriers (which in turn should stop the causes).

For the development of this model, both the Risk Influencing Factor (RIF) approach [31,43] and the Dynamic Risk Analysis approach suggested by Paltrinieri and Khan [44] were taken as a reference. Such approach is also inspired to the aforementioned Risk Barometer [22–24] and TEC2O [25]. For this reason, the main model elements (status of causes and performance of barriers) are defined by means of indicators, as explained in table 1.

The status of the causes is expressed on a scale from 1 to 6, where 1 is unlikely and 6 is very likely. This value is then multiplied by a probability of failure of the safety barrier, which is the result of the performance assessment by means of the indicators (table 1). Thus, if the barrier can completely stop the cause, or the top event, the conditional probability will be equal to 0. If the barrier is negligible or impaired, the associated conditional probability will be equal to 1.

While “Excessive Sand Production” is an independent cause, “Corrosive Environment” and “Under Deposit” should occur together in order to result into the top event. The latter two causes may be assessed singularly and assigned a weight on the basis of their effect on material degradation. Expert judgment is used for this task.

The status of material degradation is obtained by summing up contributions from the branches, after considering the effect of the preventing barriers (table 1). This value is multiplied by the probability of failure of the mitigation barriers to obtain the risk of loss of containment (table 1).

Assessment of cause status

Cause status is defined by a set of indicators. In this case, these indicators correspond to detection results from the mentioned sensors. Other types of indicators can be considered, but they should be measurable and indicate the presence and/or extent of the cause.

However, not all the indicators have the same degree of relevance. For this reason, weights should be assigned to them in order to define the cause status by means of a weighted sum. In this way, the cause status is expressed by a number from 1 to 6 (table 1).

Assessment of barrier performance

The assessment of barrier performance is based on two activities: i) Definition of the barrier structure (technical and

operational barrier measures); and ii) identification of suitable indicators.

Each barrier is the result of a synergy of various measures, such as detection or procedure measures. They play a part in realizing the task or role of the barrier and their performance is essential for the overall performance of the barrier. The measures of a barrier can be technical or operational and may have a different relative importance in the barrier structure. For this reason, each barrier considered in this contribution is broken down into measures and for each measure a specific weight is assigned.

Indicators are defined to assess also barrier performance. This type of indicators aims to report whether the measure can deliver the desired outcome. They should be measurable values and weights should be defined for them, in order to consider also their relative importance. The indicators are used to assess the barrier measure performance by means of a weighted sum. The measure performance values in turn contribute to define the overall performance of the barrier (table 1).

Collection of indicators from sensors

The huge amount of available information collected through heterogeneous devices, namely sensors, may be used as indicators to assess status of causes and performance of barriers. Different types of sensors have been mentioned for the cases addressed: ASD, erosion probe, sensors measuring stress on pipes and acoustic multibeam sonars. In such scenarios, data fusion, i.e. collective processing of possibly-heterogeneous information coming from various sensors for a final assessment, represents a key technique for effective system design.

The spatial extent of the observed process usually makes wireless technology preferable for the communication of the sensed information and often centralized architectures with a fusion center responsible for data fusion are preferred. Wireless sensor networks have been studied from multiple points of view during the last years with application in different research contexts and distributed detection through a wireless sensor network is currently an active area for research: in a typical example, many sensors transmit their local decisions to a fusion center which then takes a more-reliable global decision by appropriately combining the received information (figure 3).

The key points are: (i) exploiting the diversity provided by the spatially-distributed sensor network for robust decision, and (ii) exploiting multiantenna and array processing for effective data fusion design. Pioneering works have been based on a parallel access channel [45], where each sensor is provided with a dedicated (orthogonal) channel to communicate with the fusion center, i.e. there is no interference among sensor transmissions. Orthogonality is usually achieved through techniques based on frequency or time division multiple access. Unfortunately, employing such interference-free feature in a practical system implies large bandwidth requirements for simultaneous transmissions or alternatively a large detection delay, which may be unfeasible in large-scale sensor networks.

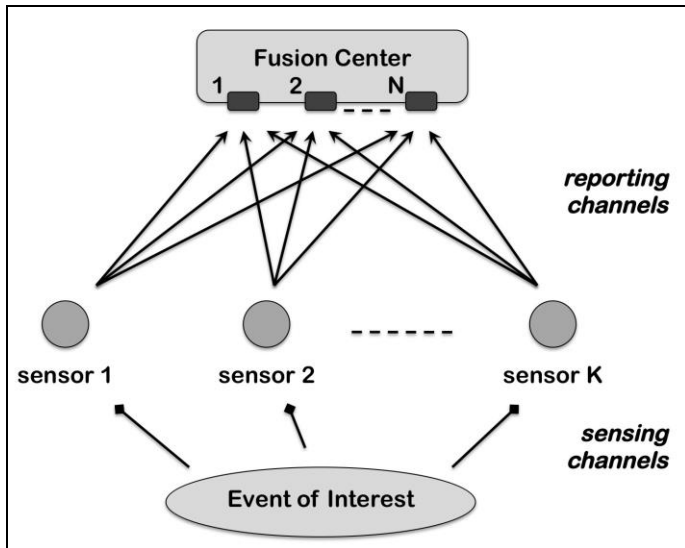


Figure 3. Typical example of network of sensors transmitting to a fusion center

Recently, the intrinsic interfering nature of the wireless medium has been exploited in the context of wireless sensor networks for distributed detection. A multiple access channel has replaced the parallel access channel for improving bandwidth efficiency [46] and the advantage of multiple antennas at the fusion center has been analytically analyzed using the error exponent [47]. Looking at the network as a “virtual” multi-input multi-output (MIMO) system, array processing techniques at the fusion center have been investigated and compared in terms of performance, complexity, and system knowledge requirements [48]. Also, the impact of massive MIMO (one of the most promising wireless technologies currently under development), in wireless sensor networks has been pioneered in [49], showing large energy saving and near-optimal performance coupled with simple processing design.

Focusing on scenarios such as anomaly detection, which is of paramount importance in the industrial applications considered, it is apparent how instantaneous channel state information may be inefficient to acquire. In such cases, the use of incoherent modulation represents a valid solution which results near-optimum from an energy point of view. Within this framework, energy detection has been analyzed in underwater scenarios [50] and in arbitrary wireless channels [51].

SIMULATION RESULTS AND DISCUSSION

The simulation performed is based on the work carried out by Paltrinieri and Hokstad for an analogous case [24]. A set of indicators was used for the causes in figure 2 and a structure with specific technical and operational measures were outlined for each barrier. Table 2 lists all these elements, but, for the sake of brevity, only some examples of indicators are reported.

Table 2. Model simulation at the times t_1 and t_2 . Adapted from Paltrinieri and Hokstad [24].

Model elements	Indicators	t_1	t_2	
<i>Excessive sand production rate</i>		Y	R	
	Acoustic sand detection	5.51	5.70	
	Erosion probe detection	2.38	5.50	
	Daily output of production data	2.34	4.95	
<i>Corrosive environment</i>		Y	G	
	Stress sensors on pipes	3.03	2.84	
<i>Under deposit</i>		Y	Y	
	Daily output of production data	4.26	2.49	
	Inspection results	3.54	4.32	
<i>Sand response procedure</i>		G	R	
	Age of the system	2.07	5.22	
	Erosion probes	3.53	4.89	
	Manual well-flow sampling	5.43	5.97	
Response to sand detection	Formalization and availability of procedure	2.18	5.00	
<i>Chemical treatment</i>		Y	R	
	Capacity of injection	3.28	1.96	
Managing chemical treatment	Competence and training	1.46	6.00	
<i>Cleaning pigging Maintenance</i>		Y	R	
	Compliance to schedule	2.69	4.39	
Managing pigging/equipment selection	Experience	2.69	3.52	
<i>Material degradation</i>		G	DR	
		Y	R	
<i>Operational strategy</i>	Regular inspection	Overdue inspection	2.60	5.76
	Unscheduled inspection	Formalization and availability of procedure	3.17	5.30
Production strategy	Competence and training	5.05	4.77	
<i>Loss of containment</i>		W	R	

The model was applied in two different scenarios (represented by the times t1 and t2) with different indicator values. In the first scenario (t1), the values of the indicators are completely random and can possibly simulate an average condition of the system. In the second scenario (t2), the representative indicators shown in table 2 describing the cause of “Excessive sand production rate” and the related barrier (“Sand response procedure”) were given values between 5 and 6, to simulate a critical condition of sand production. Moreover, the mitigation barrier “Operational Strategy” was defined as poorly performing. All the other input data, such as weight were kept constant.

The results illustrated by table 2 show a representative example of how real-time data provided by sensors and other different sources may allow dynamic assessment of risk of loss of containment. The status of causes and top event, the performance of the barriers and the risk of loss of containment are visualized by means of a color scale, as suggested by Paltrinieri and Khan [44]: 1-2 White (W); 2-3 Green (G); 3-4 Yellow (Y); 4-5 Red (R); 5-6 Dark Red (DR).

The simulation primarily addresses the hazard of sand production, for which continuous monitoring is essential to provide an effective management of the safety barriers in place. Redundant multiple sensors may be applied not only to evaluate the status of the main causes of pipe material degradation, but also to assess the performance of safety barriers themselves. Redundancy of data input is needed in order to ensure the needed degree of reliability in the data inputs.

The model for dynamic risk assessment is also of paramount importance for a case of oil platform in an environmentally sensitive area. Especially in the aforementioned case of the first FPSO in the Barents Sea. In fact, the intertwining of strict environmental requirements and advanced technologies may potentially lead to emerging unsuspected risks. For this reason, iterative evaluation may allow refining the system risk picture and provide decision-making support that may increasingly improve with experience. To this end, an additional set of sensors may allow calibrating and/or validating the evaluation of the FPSO risk level. Data from acoustic multibeam sonars detecting leakages and oil spills may be potentially compared to the assessed risk of loss of containment. In such a way, lessons can be learned once the unwanted event has occurred, by defining appropriate responses and tailored barrier improvement.

CONCLUSIONS

The contribution has suggested a specific approach for dynamic risk analysis for the offshore O&G industry. Such approach may be beneficial for several cases in which (quasi) real-time risk evaluation may support critical operations. Two representative cases have been described: i) erosion and corrosion issues due to sand production; and ii) oil production in environmental sensitive areas. In both the cases, dynamic risk analysis may employ real-time data provided by sand, corrosion and leak detectors. A simulation of dynamic risk analysis has demonstrated how the variation of such data can affect the overall risk picture. In fact, this risk assessment approach has not

only the capability to continuously iterate and outline improved system risk pictures, but it can also compare its results with sensor-measured data and allow for calibration. This can potentially guarantee progressive improvement of the method reliability for appropriate support to safety-critical decisions.

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