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A Guideline for the Dynamic Barrier Management Framework Based on System Thinking

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Accident investigations in process industry indicate that inadequate barrier management has been one of the main causes of many major accidents. Barriers degrade over time and at different rates, and these degradations may gradually and unnoticeably drift the system towards a state of high risk. Conventional barrier management approaches apply fixed inspection and maintenance intervals with little direct influence on daily operations to evaluate safety barriers performance. Such issues are addressed by the dynamic barrier management (DBM) concept through the combination of all available information, such as inspection, preventive maintenance, audit, sensors, process control, and near misses or incident records. DBM main goal is to infer barrier status in near real-time and evaluate its impact on risk level. However, the framework for DBM is not detailed and easy to implement and therefore requires further development to clarify the steps. An approach based on system thinking is suggested. Systems engineering (SE) is a suitable approach for managing complex problems by considering the big picture and the SPADE framework from SE is applied to provide a practical roadmap for DBM.

1. Introduction

Accident investigations in the petroleum industry indicate that inadequate barrier management has been one of the main causes of many major accidents (Paltrinieri et al., 2015). The Macondo blowout in 2010 (Christou and Konstantinidou, 2012) is one of the most recent representative examples. The accident happened due to the loss of well control as all the system's barriers failed to contain the hydrocarbon kick. The personnel aboard did not recognize the symptoms of a flowing well and act in time to activate the blowout preventer (BOP). The blowout led to a catastrophic fire and explosion, loss of the rig, 11 fatalities, and a major oil spill. In this case, a critical safety barrier failed, and the human decision-making was not adequate to recognize the inadequacy of the critical barriers and to formulate effective corrective actions in time to prevent the accident or mitigate its consequences.

Barriers are fully functional after their installation or commissioning, but can fail or degrade over time and the system will gradually and unnoticeably drift towards a state of high risk (Nelson, 2016). Petroleum Safety Authority (PSA, 2013) defines the main purpose of barrier management as "coordinated activities to establish and maintain 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 accident occur". In conventional barrier management approaches, the evaluation of barrier performance is assumed to be constant and determined by applying fixed inspection and maintenance intervals (Zuijderduijn, 2000). However, the barriers' performance degradation rate is dynamic and needs continual monitoring and processing of real-time data (Paltrinieri et al., 2015). Such issues can be addressed by the dynamic barrier management (DBM) approach. Pitblado et al. (2016) propose that DBM means acting on the all the available data to make proactive, timely decisions to maintain and improve barrier performance such that risk targets are met over the lifetime of a facility or activity.

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A typical North Sea offshore facility might have 2500 barrier elements whose status needs to be tracked in a variety of database and administrative systems (Hauge et al., 2015). Furthermore, barriers degrade at different rates, and some barrier failures can increase the risk dramatically, especially when barrier dependencies exist (Pitblado et al., 2016). The challenge that arises is how to set a practical roadmap to implement and use the DBM concept in daily operations in such a complex system. Monitoring safety barriers' status effectively and managing the risk in an oil and gas facility is complex and necessitates a holistic framework capable of integrating multiple datasets, assessing the status of barriers degradations and indicating the resulting impact on risk level to provide effective decision making in managing barriers during the operation phase.

Kossiakoff et al. (2011) explain that complex systems feature a large number of interacting subsystems whose aggregate activity is nonlinear and not derivable from the summation of the activities of individual components. Systems engineering (SE) is a suitable approach for managing complex problems by considering the big picture. It is widely used in the development of complex systems and successfully applied to solve a variety of complex problems. SE methodology is an iterative problem-solving approach, applied sequentially top-down by integrated teams to break down a complex system into manageable subsystems, or even down to components based on the user's needs (NASA, 2007). The focus of this work is to use systems engineering principles to assist and clarifying the steps for a comprehensive DBM guideline based on integrating available methods in barrier analysis and risk assessment update in operational decision-making.

2. Dynamic barrier management framework

Pitblado et al. (2016) defines dynamic barrier management as to act on all the available information (including direct and indirect barrier performance indicators to infer barrier status in near real-time) in order to make proactive, timely decisions and to maintain and improve barrier performance to keep the risk at an acceptable level over the lifetime of a facility or activity. In other words, barrier maintenance can be planned optimally and higher importance barriers (i.e. risk affecting ones) would be prioritized. The proposed DBM framework (see Figure 1) by Pitblado et al. (2016) consists of three loops; baseline risk, performance management, and risk mitigation.

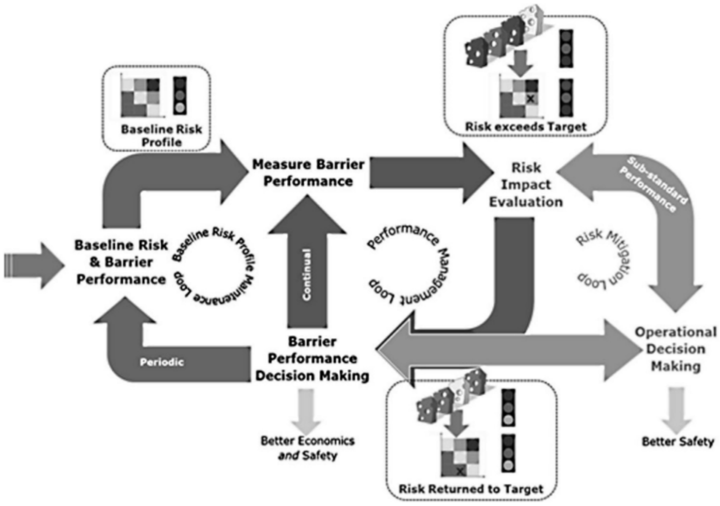

Figure 1: Dynamic Barrier Management Framework (Pitblado et al., 2016)

Baseline Risk Loop:

The purpose of this loop is to develop and maintain the initial barrier performance and risk profile. This status will be updated periodically according to the actual capabilities and barrier configuration, material changes and assumptions of risk analysis.

Performance management loop:

The objective of this loop is to identify changes that take place under operational conditions and to measure barrier performance. The results are aggregated to evaluate the overall risk level in comparison to the risk target. The outcome of this step provides sufficient basis for effective decision making regarding the barriers maintenance.

Risk mitigation loop:

This loop addresses executing immediate response through an operational decision process for mitigating the risk of an impaired/degraded barrier and return the risk level to an acceptable level. The important aspect of this stage is how to provide an effective operational safety decision in case of an emergency critical barrier failure.

3. Systems engineering

Two recent articles have demonstrated the advantages of applying SE processes to complex problems in maritime acquisition (Aspen et al., 2018) and RAMS for subsea design (Juntao et al., 2018). In both cases, SE provided a systemic and systematic discipline to collect and analyze the information available from multiple sources. Haskins (2008) devised a SE framework, SPADE, suitable to support the use of SE in non-traditional applications. The framework takes its name from the 5 activities that are critical to every SE process; identification of Stakeholders, formulation of a Problem statement, collection and Analysis of multiple Alternatives for addressing the problem, Deciding on preliminary actions, and monitoring and Evaluating outcomes and results of all activities.
The SPADE framework is applied on a representative case through the following steps: definition of Stakeholders and needs from DBM; identification of Problems related to former DBM framework; Analysis of extending DBM framework; DBM Decision-making process; and Evaluation of its effectiveness.

4. Application of SPADE to DBM framework

4.1 Stakeholders and their needs

According to the SPADE framework, an important step is to identify the system stakeholders and their needs. Freeman (2010) describes stakeholders as “any group or individual who can affect or is affected by the achievement of the organization’s objectives”. In this research, the term is used for the all the relevant groups of people or organizations that can directly or indirectly use the framework for dynamic barrier management or be influenced by using this framework. For instance, in an operational facility, some critical decision situations that can benefit from such a framework will include; work permit meetings, maintenance schedules, and operational decisions meetings. Based on this, certain potential stakeholders are the participating personnel in the planning process, maintenance and logistics, installation lead personnel, onshore and offshore management team, and field operators.

4.2 Problem formulation

Many companies in oil and gas industry implemented a proprietary barrier management for monitoring and maintenance of their safety-critical barriers with some influence on daily operations. For instance, Manual of Permitted Operations (MOPO) by Shell (Detman and Groot, 2011) and Technical Integrity Management Portal (TIMP) methodology that has been practice since 2011 in 40 Statoil sites (Jansen and Firing, 2016). According to Fisher et al. (2017) common to all the tools or approaches for operational barrier management, they attempted to either present information of barrier element status individually or on some aggregated level for specific barriers but do not directly use the effect of this information on the overall risk level.
Therefore, it is necessary for dynamic barrier management to consider the impact of risk, not just the barriers status as they become impaired or degraded. Furthermore, in order to be able to evaluate the real-time risk of a system and to give valuable decision support during operational phase based on the status of barriers, barrier management needs to assess the factors that really impact on failure probabilities and losses. This includes collecting early warnings, near misses, incidents and accident data, and barrier indicators for monitoring the changes.
The proposed DBM framework (see Figure 1) does not include the detailed steps of each loop and requires further clarification on the framework. For better understanding of the important aspects of each loop process, some key questions need to be answered:
How to set the baseline profile for barriers performance and its effect on the risk level?
How to track the effect of changes on the updating the baseline risk profile?
How to update of the status of the barrier by measuring their performance and its impact on risk level?
How to establish an effective gap analysis to identify the changes in risk profile in comparison to initial baseline?
How to provide an effective operational safety decision in case of an emergency critical barrier failure?
Furthermore, it should be noted that defining system boundaries and interfaces at the system boundaries establish the initial environment for applying the DBM framework. An important premise for establishing a DBM is the availability of data from different sources on barriers. This will vary between installations based on their age, type and novelty of safety and automation systems, maintenance system and information

management system in use. Since barrier management focuses on indicators for the status of barrier systems and barrier elements (Hauge and Øien, 2016), it is necessary to have good knowledge about what information is available for technical, operational and organizational barrier elements and which information provides suitable indicators.

4.3 Analysis

Systems analysis studies the needs, system function and structure, and the proposed solutions to an identified problem (Liu, 2015). DNV-GL (2016) defines a three-phase process for effectively updating an operational risk assessment: screening, re-evaluation, and implementation. Similar approach has been adopted for DBM framework to identify the steps that clarifies the interactions between each stage of the barrier management.
Screening Phase:
The goal of this phase is first to establish a design baseline for barrier performance monitoring and its effect on the risk level, and then tracking the changes that may affect the validity of the baseline profile. This process may be divided into three steps: a context model, categorization of system changes, and gap analysis. Each step is briefly introduced as follows:
Baseline risk profile model: Hauge et al. (2015) in the handbook for monitoring of safety barrier status and associated risk in operational phase has provided a number of steps that can be used to establish a context model for baseline risk profile, such as the Risk Barometer.
Categorization of changes: According to DNV-GL (2016) the three major categories that may occur include change in context, change in knowledge, or change in conditions.
Gap analysis: This step reviews the effect of the identified changes in the previous step by performing gap analysis on barrier elements, barrier function, and barriers systems performance and assessing the effect this has on the risk level. An identified gap may require either establishing a maintenance activity for a degraded barrier or taking operational safety decisions.
Re-evaluation Phase:
The purpose of this phase is to evaluate and decide on measures for barrier management and to establish relevant risk treatment operational decisions in order to keep the overall risk under control. Any loss, impairment or degradation of one or more barrier elements that have been identified in the screening phase, should continuously be evaluated and fixed immediately. If the failure of a safety barrier requires a prompt response and its effect on risk becomes intolerable, then an operational decision making process evaluates the risk treatment options to return the risk to an acceptable level. However, a subsequent barrier management strategy is also required to support the process of establishing the remediation of the failed barrier.
Implementation phase:
Following the previous phase's outcomes, the evaluation of barrier performance and changes in risk level may trigger a need for modification of an actual design for a barrier element, improvements within the safety-critical procedure, change in maintenance intervals for a particular part of the system or process, implementation of new barriers if the overall risk level has raised dramatically. Furthermore, in case of a permanent change (technical, operational and organizational) within the system, barrier performance strategy and baseline risk profile need to be updated accordingly. Figure 2 shows the suggested flowchart for DBM framework, comprising three phases that have been discussed in this section.

4.4 Decision making

Trade-off analysis supports decisions in all phases of system development (Kossiakoff et al., 2011). At all times, oil and gas managers are concerned with quality, time, cost and performance issues, and they try to reduce contradictions and reach a compromise. Thus, a variety of decisions requires a trade-off analysis during the establishment of the DBM tool. A trade-off analysis should be applied for the following issues:
- Which data sources should be considered for the barrier management?
- How to aggregate different data sets for the meaningful result for indicators?
- How the risk assessment will be carried out? Quantitative or qualitative modelling?
- How the result of the assessment tool will be visualized?

Although collecting more data for barrier management provides a bigger, more comprehensive picture, developers should heed the advice that "no matter how good the tool or analyst, overzealous efforts to generate and aggregate huge amounts of data into one place diminish the value of good data because it is lost in the noise of worthless data" (Zimmerman, 2014). Furthermore, the issue of the aggregation of barrier status on risk requires a detailed analysis and the companies' willingness to apply a quantitative or qualitative approach might affect the accuracy of the assessment. Thus, concerning the trade-offs, a reasonable compromise should be made for data analytics and risk modelling.

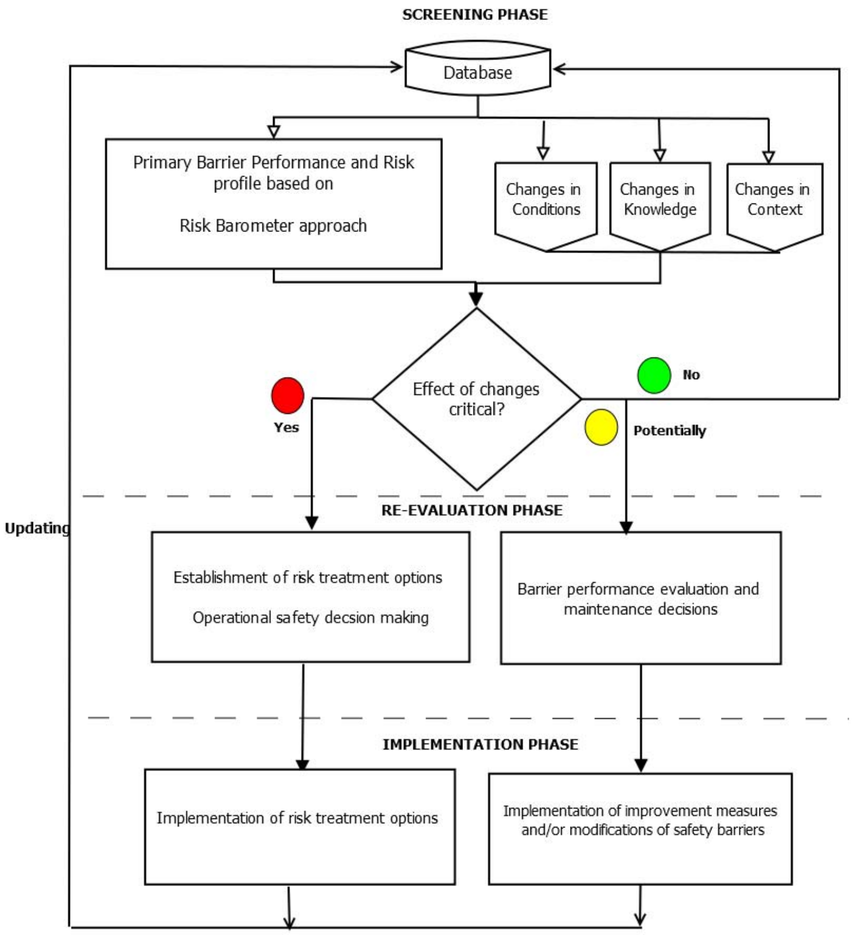

Figure 2: Proposed DBM flowchart

4.5 Evaluation

According to the SPADE framework, evaluation appears in the center of the model because it is continuous and applies to all the other activities (Haskins, 2008). Stakeholders need to be continuously monitored, this includes recognizing new stakeholders and allowing their new viewpoints to influence the operational barrier management. The problems and shortcoming of the barrier management must be continuously reviewed to ensure that the new constraints or issues raised by stakeholders are incorporated within the DBM tool. The trade-off for alternative solutions is a process of repetitive evaluation of available options and decisions to proceed with or drop a specific approach. Since no solution will ever be perfectly satisfactory or operate in a static, unchanging environment, this cycle continues until the stakeholders' needs are satisfied, or the operational environment reaches end-of-life.

5. Discussions and conclusions

As shown in Figure 2, the screening phase starts with collected data from different sources integrated in a database as input for calculating indicators value and any changes within the system that can influence these values. The screening phase process is suggested for DBM framework baseline risk loop to identify changes compared to the operational and design bases for barriers performance and risk level and to establish if the effects of these changes are understood and/or critical. This phase has then used as input for deciding whether updates are necessary and establishing possible maintenance or operational safety decisions in for the next step. Re-evaluation process is considered as an integral part of management performance loop and risk mitigation loop of the DBM framework. For example, if the identified gap is critical because of a barrier failure, then it is necessary to establish relevant risk treatment option to keep the risk under control and subsequently identifying possible remediation or maintenance strategy for the failed barrier. Following re-evaluation phase, the important changes within the operational conditions or maintenance activates are communicated to relevant stakeholders and identified decisions will be implemented. The implementation phase can be regarded as the decision-making output of the DBM framework. It should be noted that, the outcome of the implementation phase may affect the validity of primary barrier performance and target risk level, since it is necessary to consider the new knowledge by updating the baseline risk profile.

The aim of barrier management is to establish and maintain barriers to handle the ambient and operational risk faced at any given time. Therefore, the performance of the barriers must be monitored, followed up, and where necessary improved throughout the facility's life cycle (PSA, 2013). The problems of current DBM framework is discussed and the possible solution for clarifying the framework steps are analyzed. This work proposes the use of the SPADE process to support a systemic and systematic evaluation of the DBM framework introduced by Pitblado et al. (2016) to achieve a guideline that identifies the needs and steps for implementing an effective DBM, as well as, defining a trade space for considering available options to support the decision-making process. Furthermore, a flowchart is suggested for the DBM by mapping the relevant framework loops to the flowchart phases to provide clarifying recommendations for actual implementation.

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