A Framework for Developing Leading Indicators for Offshore Drillwell Blowout Incidents

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Offshore operations have always been very challenging due to technological and operational complexities in combination with harsh environmental conditions. Geological uncertainties, high pressure flammable fluids in the presence of ignition sources, complicated structural layouts, limited response time allowance, difficulty of control and communication are some of the critical factors that pose clear threats towards safe operations and may result in high consequence events *i.e.*, blowouts. Developing well specified risk indicators is difficult due to such highly correlated factors and multifaceted operations. Leading indicators, which are able to identify critical events that could lead to high consequence events, have proven to be an effective tool that can help the operators in their decision making to react earlier to an event and to reduce the risk of an incident. Most of the research dedicated to leading and lagging indicators are applicable to the petrochemical industry, and there is not yet an agreement on a definition and classification of leading indicators related to drilling related blowouts. This paper discusses the approaches of different organizations and institutes on leading indicators characterization and development. The drilling industry is compared with the aviation industry to identify potential elements for developing a comprehensive leading indicators based risk model. A workable definition of leading indicators is proposed considering the intricacy of offshore operations. Leading risk indicators are broadly categorized into two classes which are further segmented into different groups. Proposed categorization is analyzed with a blowout case study and simple decision support algorithms are proposed for detecting gas kicks which are major precursor to blowouts.

Keywords: Leading indicators; Risk metrics; Offshore blowouts; Risk assessment; Predictive tool

Introduction

Blowouts are considered to be the most notorious events in drilling operations and have caused hundreds of fatalities and injuries, millions of barrels of oil release to the environment and billions of dollars of property damage over the last few decades. As per US Bureau of Safety and Environmental Enforcement (BSEE) and US Bureau of Ocean Energy Management (BOEM) statistics, from 1980-2011 a total of 77 blowouts and 32 major well release events were reported from 31,574 drilled wells in US Gulf of Mexico [BOEM, 2014]. The picture is almost similar in other parts of the world. Many catastrophic events resulted from uncontrolled well releases while drilling or during other well-related activities. For instance, in recent times, the Deepwater Horizon blowout in the US Gulf of Mexico caused 11 fatalities [Marsh, 2013] and about 4.9 million barrels [U.S. Coast Guard, 2011] of oil spill in 2010 and the Montara blowout in Western Australia caused about 30,000 barrels [Koh Q., 2012] of crude oil spill in 2009. But incidents like Deepwater Horizon and Montara do not just happen due to a single failure and usually result from a complex combination of deficiencies that coincide – technical or operational failure, inadequate safeguards or safety management systems, and human factors. Focus on these factors can reveal any existing inconsistencies in the system that may initiate a blowout event.

For general process industries, organizations have been using process safety metrics or risk indicators to evaluate and benchmark day to day safety performances. Historically, companies have been using lagging indicators *i.e., the total recordable incident rate (TRIR), lost time incident rate (LTIR),* number of fatalities or injuries in general to monitor and track organizational safety performances. But these are mostly personal safety measures and provide very little or no picture at all on overall process safety performances. So, industry started to consider leading indicators which are proactive or predictive measures and offer a closer look into operational and organizational safety culture. Having a workable set of process safety indicators came into discussion particularly after the Texas City refinery explosion in 2005 where the Baker panel report [Baker et al., 2007] recommended to establish leading and lagging process safety indicators to help prevent such incidents. Offshore drilling, being a very complex and high risk activity – can similarly be benefitted from implementation of well-specified leading indicators for early prediction of potential upsets.

This work is dedicated to studying the scope and methodology of developing potential leading risk indicators for offshore drilling operations focusing on blowout incidents. Flow of uncontrolled well fluids into a wellbore and to the environment is called a blowout. As blowouts are low frequency-high consequence events, lagging indicators cannot offer a good measure because having a low past incident rate or low rate of gas kick events does not eliminate or help predict the chance of a future uncontrolled gas kick resulting in a blowout. Again, drilling is a multi-stakeholder process and organizational factors play a crucial role in risk management and acceptance which can only be taken into consideration with appropriate leading indicators. This paper includes a brief discussion of existing guidelines, recommended practices and relevant industrial works for developing process safety indicators. An arrow diagram relating lagging and leading indicators in drilling operations is proposed, followed by a detailed categorization of leading indicators. For effective safety performance monitoring and incident prevention, this work proposes incorporation of real-time indicators or process observables with operational and organizational factors in leading indicators program. In the discussion section, possible utilization of real time indicators or process observables in decision support algorithms is discussed. Finally, a case analysis is presented and future aspects of this project are discussed.

Relevant Works

Recommended Practices and Guidelines

Several organizations including the UK Health and Safety Executive (UK HSE), the American Petroleum Institute (API), the International Oil and Gas Producers (IOGP) and the Institution of Chemical Engineers (IChemE) published guidelines on developing process safety indicators for different organizations – upstream, downstream or general hazard organizations. In 2006, UK HSE published a *Step-by-Step Guideline to Develop Process Safety Indicators for Major Hazard Industri*es [UK HSE, 2006]. UK HSE defines leading indicators as active monitoring systems for operational and organizational controls placed to prevent any unwanted situation and lagging indicators as reactive measures which are the desired outcome the risk control system is designed to deliver. In this guideline the concept of dual assurance was introduced where leading and lagging indicators perform in combination in a structured and systematic way of defining each critical risk control factor. The Centre for Chemical Process Safety (CCPS) published a guideline book on development and use of process safety metrics [CCPS, 2010] where they are defined as some observable measures and categorized into leading, lagging and near-miss metrics. Later, in 2010, *ANSI/API Recommended Practice 754: Process Safety Performance Indicators for the Refining and Petrochemical Industries* [API, 2010] was published. The four-tier approach of safety performance indicators was introduced with Tier 1 being the most lagging and Tier 4 being the most leading aspects of events. Until this point, the guidelines mostly focused on downstream operations, but in 2011 IOGP published a report on *Recommended Practice on Key Performance Indicators* [IOGP, 2011] focusing on upstream operations. However, the framework was built based on API RP-754 and guidelines published by UK HES, CCPS and OECD (Organization for Economic Co-operation and Development). IOGP recommends using API's four-tier approach, but also provides guidance to support upstream operations and activities. Very recently, in 2015, IChemE published a guidance document [IChemE, 2015] on leading process safety metrics for industries with hazardous activities. They developed comprehensive guidelines on selecting and tracking process safety lead metrics for six pre-classified organizational function areas.

All these recommended practices and guidelines are very useful in developing a safety indicators program for process plants but these are partly applicable to offshore drilling operations. Some of the shortcomings in applying the existing guidelines to offshore drilling scenarios include – primary focus on production related losses in most of the guidelines [Wilkinson, 2012], emphasis on consequence-based approach rather than cause-based approach and use of process operations focused language and concepts in general [Wilkinson, 2012].

Industrial Works

The Norwegian project - Trends in Risk Level in the Petroleum Activity (RNNP) in oil and gas sectors is one of the most extensive projects that studied and developed risk indicators for critical operations and installations. The steps for developing major hazard risk indicators for offshore installations were proposed and comprehensive analyses were performed with collected data from participating Norwegian Continental Shelf installations [Vinnem *et al.*, 2006; Vinnem, 2010]. Two types of major risk indicators were developed and studied– indicators based on incidents and indicators based on barrier performances. Extensive analyses on barrier performance indicators were performed with test data and sets of indicators were proposed for specific barrier elements *i.e. topside, marine etc*. The adaptability of the risk level project for preventing deepwater blowouts were also analyzed [Skogdalen *et al.*, 2011] and it was suggested to extend the study to the areas specific to offshore drilling operations, *e.g. well incidents, operators' response and others.* Some broad and useful sets of leading indicators for early warning of blowouts were proposed for five different areas related to drilling activities. But further investigation is required for identifying relevant and effective indicators for kicks and blowouts.

Approaches of a High Reliability Organization- Aviation Industry

Despite having a completely different type of business and activities, the drilling industry has some similarities with the aviation industry in terms of major hazard and risk undertaking and mode of operations. Both industries need more focus on leading indicators as major incidents are rare but the consequences are large, and in both cases several stakeholders are involved to achieve a common goal. The latter is of great importance in drilling operations because less focus is given in the consistent interaction between different parties' on a rig and this particular element came into discussion after almost every major incident. The similarity between aviation and drilling industries regarding multi-stakeholder involvement is represented in Figure 1.

The Aviation Safety and Certification of new Operations and Systems (ASCOS) framework for developing safety performance indicators for aviation systems [Roelen *et al.*, 2014] defined indicators for four levels – technology, human, organizational and system of organizations. System of organizations represents the interaction and harmony among individual organizations needed to ensure safe and reliable operations. To design and develop indicators for tracking the synchronization among the stakeholders in terms of operational performance and safety is certainly an interesting and useful concept. These indicators would allow one to monitor the interaction between different parties *i.e., operators, drilling contractors and manufacturers* on a drilling rig and ensure no compromise in safety performances at organizational interfaces.

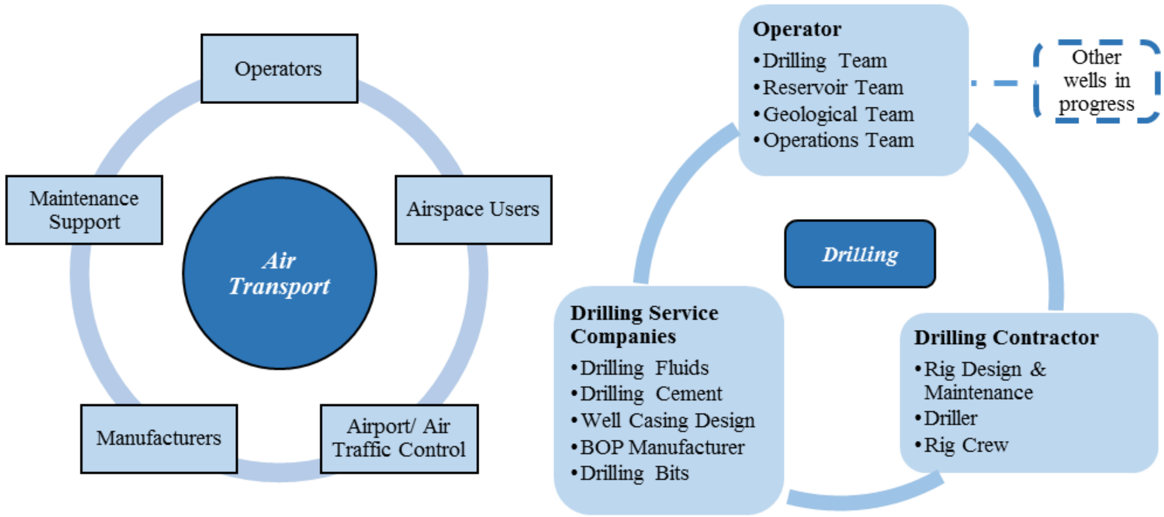

Figure 1: Multi-stakeholder operations in aviation and drilling

Leading Indicators for Drillwell Blowouts

There has been an ongoing debate on the definitions for leading and lagging indicators and the differences and clear boundaries between these two are yet to be established. In many occasions the interface is fuzzy as an event/element can serve both as a leading and lagging performance indicator. For example, a gas kick is a lagging event as well fluid has already entered into the wellbore with a barrier failure but, at the same time, gas kick is a leading indicator for a possible blowout. For simplification, in this project, all the observables and indicators that predict a potential gas kick and subsequent blowout scenario are considered to be leading indicators. A workable definition of leading risk indicators is proposed in the next section for general application. Lagging to leading transition of drilling events can be represented with following arrow diagram in Figure 2.

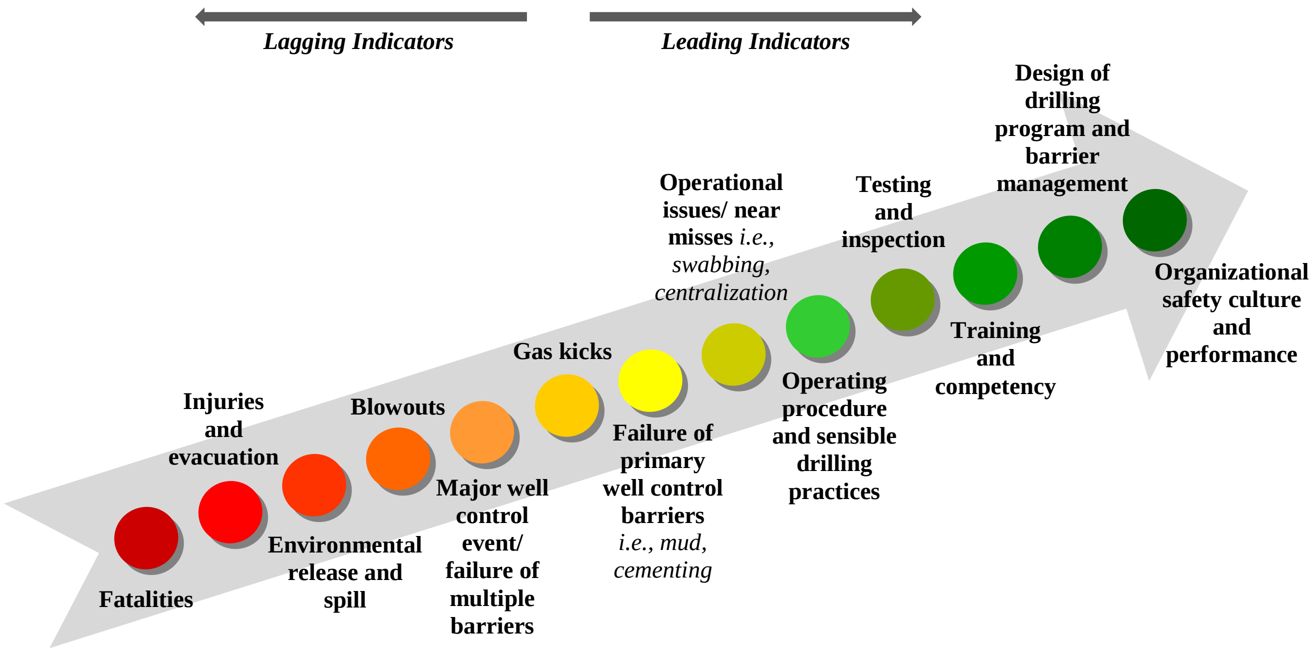

Figure 2: Gradual transition from lagging to leading indicators in drilling operations

This diagram is constructed for general drilling operations inspired by the lagging and leading synthesis scale proposed by Wang *et al.* [Wang *et al.*, 2013] for process plants. This diagram correlates lagging events with leading indicators in the same scale without differentiating between these two terms. For drilling operations, fatalities and environmental releases can be considered as the most lagging events/metrics whereas training, design and overall organizational safety culture are amongst the most leading events. Finally, other events, like gas kicks, failure of a primary barrier, and precursor events lie in a transition zone which can serve both as leading and lagging indicators based on the context.

Development of a Framework

Definition

Even though various definitions of leading indicators have been adopted in different guidelines, the basic notion is the same – they are proactive measures. The following key characteristics were outlined by analyzing the definitions provided in various sources *i.e., API, UK HSE, OGP, IChemE*.

Leading indicators -

- are considered to be a predictive set of parameters/course of actions,
- should deliver early information on barrier performance,
- must be measurable and recognizable, and
- should indicate and benchmark operational and organizational performances.

Based on these features and considering offshore operations adaptability the following definition is proposed –

“A leading indicator provides early observable signs of threat from any event which may compromise the safety of a process, personnel or the environment, by progression to an undesirable state or value”.

It should be noted that leading indicators is a general term and based on the characteristics function and application different industries use different terminologies - process safety leading indicators or lead metrics, leading risk indicators, leading performance indicators etc. Ultimately, they represent to a safety performance scenario or operational risk level.

Categorization

The categorization of leading risk indicators is done as follows:

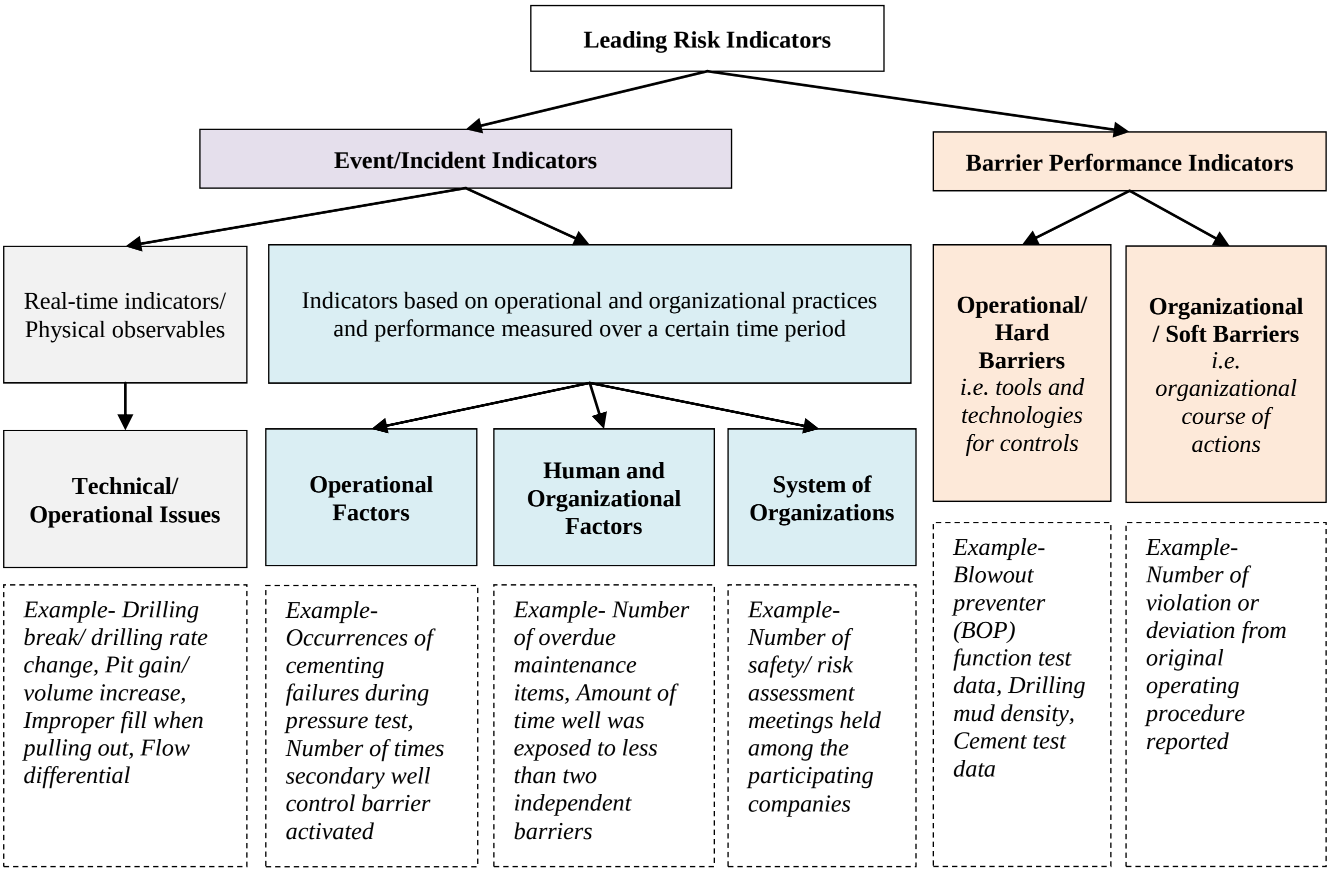

Figure 3: Proposed categorization of leading risk indicators with example

For offshore drilling scenarios, leading risk indicators can primarily be categorized in two different ways [Vinnem *et al.*, 2006] – incident/event indicators and barrier performance indicators. These two sets are not mutually exclusive as a barrier performance indicator may show the probability of a potential incident and thus can also serve as an incident indicator. Incident/event indicators are divided into two groups for drilling operations as shown in the Figure 3 – real-time indicators or short-term measures and long-term operational and organizational performance indicators. Traditionally, the latter are considered leading indicators in general. The category 'system of organization' is adopted from the aviation industry practice as discussed in an earlier section.

To establish a comprehensive set of indicators a cause-based approach is proposed with analysis of associated scenarios that could lead to a loss of well control event. At the beginning, indicators can be developed upon studying possible root causes and initiating events (technical/operational issues). Then subsequent analysis can be performed to correlate the fundamental technical or operational failures with operational performance leading to human and organizational factors. For each category, an appropriate set of performance/risk indicators can be established to track the elements affecting the safety and integrity of the total system.

Discussion

Developing a Decision Support Algorithm with Physical Observables

Indicators of different categories can be used at different organizational levels. And on a different aspect, simple decision support algorithms can also be developed correlating the physical observables with actions required to get early warning on gas kick probabilities. A general example of a possible decision support algorithm is shown in Figure 4 for conventional drilling operations.

Drilling breaks may be experienced due to entry of well fluids into the wellbore or because of some geological issues. Flow checks are the next step to check for a possible gas kick. An increase in flow rate or mud pit volume indicates a probable gas kick scenario. Similar algorithms can be developed as a decision support tool using instantaneous process indicators for specific drilling operations. By analyzing successful kick detection methodologies and from expert opinion, actions necessary to understand the gas kick scenario from physical observables and drilling data can be represented in the form of algorithms for easy and quick understanding.

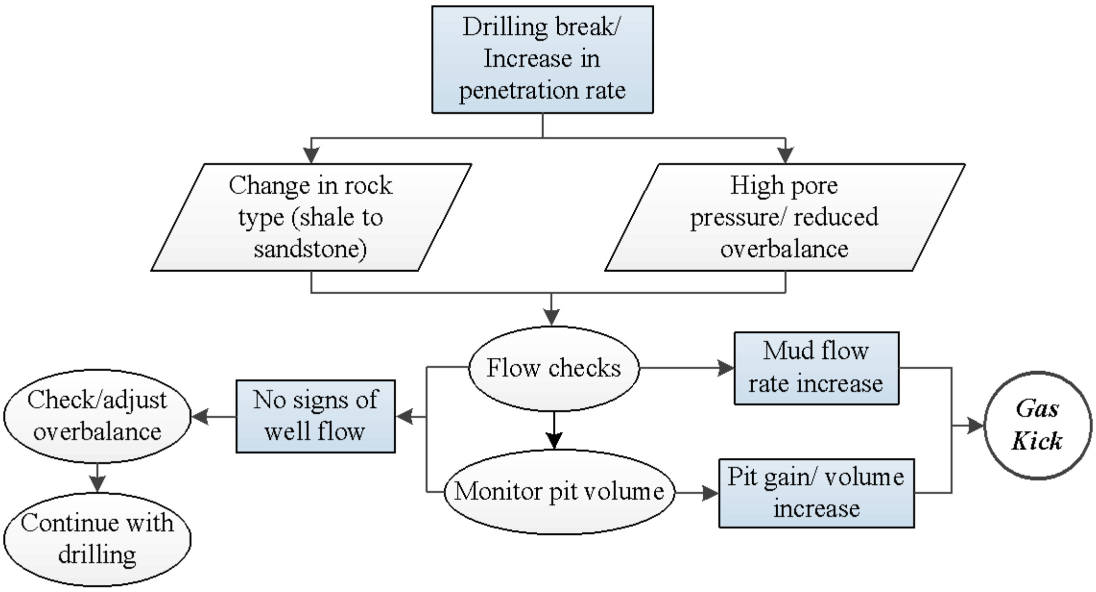

Figure 4: Decision support algorithm using process observables

Case Study: Montara Blowout

H1 well of the Montara Wellhead Platform in the Timor Sea, Australia, kicked and uncontrolled hydrocarbon started to flow on August 21, 2009 [Borthwick, 2010]. The report of the Montara Commission of Inquiry [Borthwick, 2010] revealed a series of operational and organizational issues and failures that led to this disaster. On March 2009, operations on the well were temporarily suspended with barriers – cemented casing shoe, pressure containing anti-corrosion caps (PCCC) and overbalanced well fluid. The integrity of each of these barriers was compromised and the well control system failed to prevent influx of hydrocarbons into the wellbore and eventually to the environment. A leading risk indicator program could have predicted ongoing disorders and vulnerability of the well control system. A pressure test was conducted after installation of the cemented casing shoe. Volume and pressure data showed some discrepancies which indicated possible leakage through the float valves. Two PCCCs were planned to be installed instead of cement plugs, where PCCC is not a recognized well control barrier. Even, one PCCC was not been installed which caused corrosion in the casing thread and complicated the completion operations.

A proper risk assessment program could have identified the incompatibility of PCCCs as a well control barrier, and an effective inspection and audit program could have revealed the issue of non-installation of the PCCC. Again, the density of casing fluid was not sufficient to balance the formation pressure and the absence of a long-term barrier monitoring program allowed the incident to develop. Several key organizational performance factors were responsible for the incident *i.e., lack of a risk assessment program, deficiencies in guidelines and sensible drilling procedures, lack of compliance audit and safety critical equipment/barrier management*, which are some of the critical leading risk indicator elements.

Conclusion

The background and framework of a leading risk indicators model for offshore drilling blowouts are discussed in this paper. Leading risk indicators are categorized considering the complexities of drilling operations. Leading to lagging events transition and correlations are established with an arrow diagram which could be useful in developing a risk management program. For decision support, simple understandable algorithms can be developed using process variables. A sample algorithm is presented for a potential gas kick indicator – drilling break. This work aims to develop a comprehensive leading indicators based risk assessment model for offshore blowouts. A categorized set of leading indicators along with clear guidelines to establish a risk indicators program specific to offshore operations will also be proposed in the future.

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