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A safety barrier-based accident model for offshore drilling blowouts

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ABSTRACT

Blowout is one of the most serious accidents in the offshore oil and gas industry. Accident records show that most of the offshore blowouts have occurred in the drilling phase. Efficient measures to prevent, mitigate, and control offshore drilling blowouts are important for the entire offshore oil and gas industry. This article proposes a new barrier-based accident model for drilling blowouts. The model is based on the three-level well control theory, and primary and secondary well control barriers and an extra well monitoring barrier are established between the reservoir and the blowout event. The three barriers are illustrated in a graphical model that is similar to the well-known Swiss cheese model. Five additional barriers are established to mitigate and control the blowout accident, and event tree analysis is used to analyze the possible consequence chains. Based on statistical data and literature reviews, failures of each barrier are presented. These failures can be used as guidance for offshore drilling operators to become aware of the vulnerabilities of the safety barrier system, and to assess the risk related to these barriers. The Macondo accident is used as a case study to show how the new model can be used to understand the development of the events leading to the accident. The model can also be used as an aid to prevent future blowouts or to stop the escalation of events.

1. Introduction

Offshore drilling, especially deepwater drilling, is a high-risk and high-cost operation, and blowout is one the most serious accidents to a drilling rig and its crew. Oil spill caused by offshore blowouts may result in massive damage to the maritime environment and eco-systems. The Macondo blowout, which caused 11 fatalities, a lost drilling rig, and the largest marine oil spill in the history of the petroleum industry, warns operators that the vigilance to blowouts should never be reduced.

Skogdalen, Utne, and Vinnem (2011) propose measures for preventing offshore oil and gas deepwater drilling blowouts in the various life cycle phases of a well. Their goal is to develop safety indicators that can be used to *prevent* offshore drilling blowouts, and possible barriers to mitigate and control blowouts are therefore not examined. Haugen, Seljelid, and Nyheim (2011) present a risk model for blowouts according to the time sequence of the operations. The model provides relevant risk-influencing factors related to blowout risk, but barriers after the blowout event has occurred are not analyzed in their research. Pitblado and Fisher (2011) propose an incident investigation method built on barrier-based risk assessment diagrams (bow-ties), called BSCAT. The well-established *loss causation model* (Bird, Germain, & Clark, 2003) is used to identify the root causes of the incident. By considering the barriers, one-by-one, this method makes the incident investigation rather straightforward. The BSCAT method might also be used to identify root causes of a specific offshore drilling blowout, and to establish an accident model for offshore drilling blowouts. Unfortunately, such a model has not been established.

The objective of this article is to build an accident model for offshore drilling blowouts based on the *Swiss cheese model* (Reason, 1990). The model will explicitly present the accident progression of an offshore drilling blowout and may be used as a “living” model to prevent future blowout accidents or to intervene into a blowout accident to stop the development, and delimit the damage.

The rest of this article is organized as follows: Section 2 introduces the Swiss cheese model and presents its application in offshore process safety. Section 3 introduces the concept and classification of safety barrier, and discusses barriers in a well. The proposed model, which is based on the three-level well control theory and the Swiss cheese model, is presented in Section 4. The Macondo blowout is analyzed by using the proposed model in Section 5. Finally, conclusions are given in Section 6.

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2. The Swiss cheese model and its application in offshore process safety

Accident models can be classified into three categories: (a) sequential models (or simple linear system models), (b) epidemiological models (or complex linear system models), and (c) systematic models (Hollnagel, 2004; Lundberg, Rollenhagen, & Hollnagel, 2009). Sequential models are the simplest, and are often in line with our natural understanding of accidents. These models focus on preventing accidents in comparatively simple systems, e.g., for an operator working with a machine. Epidemiological models can be seen as a response to the demand for more powerful and more complex accident models, and are more comprehensive and better suited for analysis of complicated systems. An important feature of epidemiological models is the concept of latent conditions, which remind the accident investigators to analyze deeper into organizational factors to prevent future accidents. Systematic models describe the characteristic performance on a system level, rather than on the level of specific cause-effect mechanisms or even epidemiological factors. A noticeable feature of systemic models is the sharp end—blunt end relationships that extends the scope of accident analysis to regulators and the government level – even morals and social norms will be analyzed.

There are two reasons for choosing the Swiss cheese model as basis of the proposed model in this article:

1. The well control operations can be divided into distinct phases (see Section 3.2) and these operations can be considered as safety barriers in the Swiss cheese model.
2. The proposed model is intended to be used by offshore drilling contractors and operators to identify vulnerabilities in their safety barrier systems, and thereby to prevent, control, and mitigate blowouts. This is analogous to the Swiss cheese model.

Reason (1990) claims that accidents can be seen as the result of interrelations between real time "unsafe acts" of operators and latent conditions. He formulates his views based on the Swiss cheese model in Fig. 1 (Reason, Carthey, & De Leval, 2001). The model is highly pedagogical and has been used by a large number of safety analysts around the world and in many different industries (Reason, Hollnagel, & Paries, 2006).

Kujath, Amyotte, and Khan (2009) propose a special version of the Swiss cheese model for oil and gas process accidents with five categories of barriers.

1. Release prevention
2. Ignition prevention
3. Escalation prevention
4. Harm prevention
5. Loss prevention

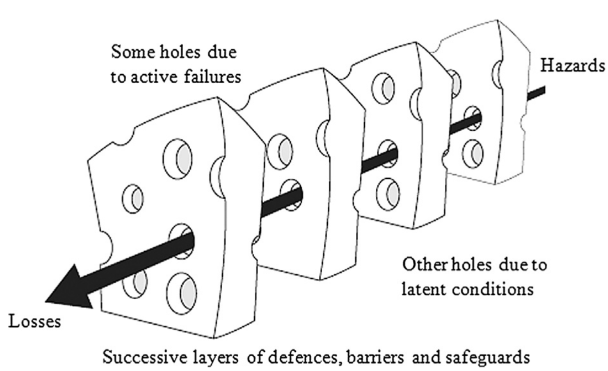

Fig. 1. Swiss cheese model adapted from Reason et al. (2001).

Their accident model starts by reducing the likelihood of hydrocarbon release and applies successive safety barriers to minimize the escalation of events. Each safety barrier is further branched to highlight applicable safety barrier sub-elements. The accident model of Kujath et al. (2009) is extended by Rathnayaka, Khan, and Amyotte (2011), who add a safety analysis procedure that demonstrates how their process accident model is integrated into process system safety. The analysis procedure is called *system hazard identification, prediction, and prevention* (SHIPP). Their extended process accident model is shown in Fig. 2 and has five main safety barriers in a sequence together with two additional barriers that influence these five barriers, a management and organizational barrier and a human factor barrier.

The oil company Shell has adopted the TRIPOD methodology (Hudson et al., 1991, 1994) for safety management. In TRIPOD, accidents occur when unsafe acts and triggering events outdo the available defenses. Underlying causes behind the immediate failures are regarded as important in TRIPOD and are latent failures that are present for a long time. TRIPOD is also derived from the Swiss cheese model.

The Swiss cheese model is a conceptual framework and is a heuristic explanatory means for communicating how accidents can occur in complex systems. It conveys the fact that no single failure, human or technical, is sufficient to cause an accident. On the contrary, an accident involves the coexistence of several contributing factors arising from different levels of the system (Reason et al., 2006). The Swiss cheese model presents a simple, but effective way to model a specific accident. To build the Swiss cheese model for a specific accident, the analyst needs to identify the barriers, and then their failures. Barrier (or defense) is the basic element in this model. In the next section, the safety barrier concept is introduced.

3. Safety barrier

3.1. Definition and classification

A *safety barrier* is implemented to protect people, the environment, and assets from hazards or dangers. Different terms with similar meanings (barrier, defense, protection layer, safety critical element, etc.) have been used in various industries, sectors, and countries.

To formally define the concept of safety barrier, we first need to define the term safety barrier function, which is "what" is needed to assure, increase and/or promote safety (De Dianous & Fievez, 2006). Rausand (2011) divides safety barrier functions into proactive and reactive functions according to if their service time is before or after a specific undesired event. Barriers that are intended to function before an undesired event are proactive, while barriers that are intended to function after the event are reactive. In the ARAMIS project, safety barrier functions are divided into "to avoid", "to prevent", "to control", and "to limit, reduce, or mitigate" (De Dianous & Fievez, 2006). Based on experience from a literature survey concerning the understanding of safety barriers in different industries, Sklet (2006) defines safety barrier function as:

A barrier function is a function planned to prevent, control, or mitigate undesired events or accidents.

Prevent means reduction of the likelihood of an undesired event, control means limiting the extent and/or duration of the event to prevent escalation, and mitigate means reduction of the effects of the undesired event.