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Implications of novel risk perspectives for ice management operations

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ABSTRACT

Ice management enables offshore and marine activities in Arctic waters in the presence of sea ice or icebergs. The presence of ice introduces additional risks to the activities. This paper discusses the risks in the light of novel risk perspectives, emphasizing uncertainties arising from potentially weak background knowledge in ice management operations. An ice management system is defined and a generic risk picture of an ice management operation is created. Risk theory is connected to the results using discussion and a conceptual example. Ice management operations are complex socio-technical systems requiring expertise in various fields. Available data is scarce and uncertainties are high. Still, the main activities need to trust in the ice management system to operate safely. The risks in ice management operations culminate in decision making and physical ice management. These need to be better understood to manage the operational risks.

1. Introduction

Ice management can be defined in many ways (Eik, 2008; Browne and Connelly, 2014; ISO, 2010). In this paper, ice management is seen as a systematic operation enabling a main activity that could not be safely conducted without additional actions due to potential existence of sea ice or icebergs. These main activities can include, but are not limited to, operations related to offshore oil and gas exploration, production, loading and offloading, subsea or marine construction, wind and wave energy production, scientific research, and fish farming.

Offshore activities that conventionally have been conducted in open water conditions are made possible by ice management also in the presence of ice. However, operating in ice introduces a new element of risk for these activities. Any activities in the Arctic that have potential for negative environmental consequences are socially and politically delicate issues. The related risks need to be well understood and communicated to get a license to operate, and equally important, a public acceptance for the activity. See e.g. NEB (2011, 2014) and Aven and Renn (2012).

Some risk models for ice management operations are presented in the literature. For example,Eik and Gudmestad (2010) introduced an event tree for iceberg collisions and Farid et al. (2014) proposed a hybrid model of Bayesian networks and fault trees. These models concentrate on quantifying the probability of a specific event and do not properly assess the uncertainties related to the analysis. A fundamental discussion on risks related to ice management operations is also missing in the literature.

The aim of this paper is to discuss the risks arising from operating in ice, while supported by an ice management operation, in the light of an advanced theoretical risk perspective, and give a holistic view on the risks associated with an ice management operation. The focus is on uncertainties arising from the lack of knowledge about various elements of the operational environment and the ice management operation itself. The purpose is to advance more thorough risk assessments for ice management and thus enable more effective and safe comparison of design alternatives and planning of operations.

Within the scope of this paper are all ice management operations conducted to protect stationary or near stationary marine or offshore activities (main activity) that are not designed to independently withstand all possible ice conditions. This paper only addresses the risks to the main activity associated with the ice management operation and does not address the risks with the main activity itself, such as drilling and offloading. Ice breaking to assist winter navigation, harbour operations and similar shipping-related operations are excluded. Winterization or facility maintenance, such as icing prevention and ice clearing from structures and equipment, are not considered to belong under ice management in this context.

The uncertainty-based novel risk perspective has been discussed recently in connection with other applications. For example, Milazzo and Aven (2012) discuss the approach for pipe ruptures in chem-

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ical plants, Aven and Pedersen (2014) apply the perspective in a subsea production system assurance analysis, and Goerlandt and Montewka (2015b) use the perspective in analysing risk in maritime transportation. Discussion on the risk perspectives in different application areas is seen as an important contribution to the literature (Aven et al., 2015) .

2. Review of ice management operations

Ice management to support station keeping in ice has been conducted in oil exploration projects since 1976 in the Canadian Beaufort Sea and later in the U.S. Beaufort Sea to manage the ice and extend the drilling season of drillships primarily intended for open water use (Dunderdale and Wright, 2005; Hinkel and Thibodeau, 1988; Wright, 1998). A conical drilling unit, the Kulluk which was designed to withstand significant ice loads, started drilling operations in the Canadian Beaufort Sea in 1983. The operation was supported by anchor handling and supply icebreakers also performing physical ice management when required. The operations and the performance of the Kulluk are described for example in Pilkington et al. (1984) , Sayed et al. (2012), and Hnatiuk and Wright (1984). The first ice management operation to support Dynamically Positioned (DP) station keeping was conducted offshore Sakhalin Island in 1999 to support diving and construction operations (Keinonen et al., 2000). The first, and so far only, ice management supported operation, where oil has been produced, was also offshore Sakhalin Island (Keinonen et al., 2006a). A scientific Arctic Coring Expedition, trying the limits of an ice management system and DP station keeping in ice, was conducted in 2004 in the central polar pack (Keinonen et al., 2006b).

Iceberg management is seen as one form of ice management and it concerns mainly operations in open water, but in an area where iceberg incursions can occur. The first iceberg management techniques were developed in offshore eastern Canada oil exploration projects already from the early 1970s. Year-round oil production started in 1997 at the Hibernia field offshore Newfoundland and iceberg management has been an important part of the activity since (Crocker et al., 1998). Eik (2008) has written a comprehensive review on the past projects involving ice and iceberg management.

Most of the past projects involving ice management have been about petroleum activities. This is apparent as very few offshore or marine activities have such potential gains that would justify the use of costly supporting operations such as ice management. Hamilton et al. (2011) calculate that approximately half of the estimated 82 billion barrels of Arctic oil will lie deeper than 100 m water depth, requiring floating exploration and production systems and consequently a supporting ice management operation. Kubat and Sayed (2014) have written a wide literature review concentrating on the technological challenge of station keeping in ice.

3. Theory and methods

3.1. Risk perspective

Many concepts of risk are used in science and engineering (Aven, 2012). In order for a risk assessment to make sense, the meaning of risk needs to be defined. The so-called novel risk perspective adopted in this paper is based on Aven (2008), further refined in Aven (2013), Aven and Krohn (2014), and Aven (2015). Risk is about the uncertainty (U) of future events or activities (A) and their (negative or positive) consequences (C). So risk is defined as a combination of events, their consequences and related uncertainty (A, C, U). Risk is described by giving predictions of the events (A'), their predicted consequences (C'). These are predictions (′) since they are future events which cannot be accurately known. The uncertainty is described with a measure (Q). Both predictions and the measure of uncertainty are conditional on our background knowledge (K). The risk description then becomes a combination of (A', C', Q, K). Subjective probabilities (P_S) are commonly used as the measure of uncertainty (Q), but other, for example qualitative means are possible.

The probabilistic approach does not fully cover all elements of risk. Rare or surprising events with potential for severe or even extreme consequences, also referred to as Black Swans (Taleb, 2007), need a separate consideration in a complete risk assessment. These events are easily left out from the analyses due to their negligible probability or hardly identifiable nature. Aven (2015) classifies these events into three categories:

- *Unknown unknowns*, which are events unknown to the scientific community: a totally new type of extreme weather phenomenon, for example.
- *Unknown knowns*, which are events known to someone, but not the persons involved in the risk assessment. These events are not considered by the risk assessment and therefore their occurrence comes as a surprise, such as an extreme weather phenomenon known by a local population to occur occasionally, but undocumented and hence totally unknown to the meteorologists involved in the risk assessment.
- *Events judged to have negligible probability of occurrence*. These include extreme events that were considered in the risk assessment but removed from the model or final results because they were judged to occur with such a low probability that they can be omitted — an ice island drifting to an area where icebergs have never been sighted, for example. Such events can still occur, even if the probability is judged to be very low.

As a summary, the novel risk perspective consists of three main aspects: probability-based thinking, knowledge dimension, and surprising or rare events. A thorough risk assessment needs to consider all of these.

3.2. Ice management system

Studying the risks related to an operation in a structured manner requires system thinking (Haimes, 2012). The usually many components and complex processes involved in an operation can be classified and systematized in several ways, depending on the viewpoint and purpose for doing so (Ayyub, 2003). Here, the viewpoint is a bird's eye view, looking at the ice management system objectively from above. As each ice management operation is unique and there is no such thing as a standard operation, the systematization here is kept at a high level to be applicable to different operations.

The system elements are identified from literature (see Section 2) and by interviewing people who have operational ice management experience. They are categorised based on their type or nature, so that specific methods could be applied to identify and quantify the risks related to a specific category.

Although the ice management system is considered here as a separate system or a sub-system of the main activity, in reality it works as an integrated part of the main activity or at least in very close co-operation with it. The separation made here is a logical boundary between the ice management operation and the main activity. The ice management system defined here has inputs, which it processes through system functions and which further exit the system as outputs. Fig. 1 illustrates the ice management system.

The system inputs are divided into two categories: the *ice input* and the *information input*. The *ice input* consists of the parameters of the sea ice that is to be managed. These are the encountered ice