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DRILLING WASTE HANDLING PRACTICES IN LOW TEMPERATURE OPERATIONS: A RISK PERSPECTIVE

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ABSTRACT

To make drilling waste handling practices safe, in low temperature operational conditions, the integration of risk-based assessment and management systems seems promising. The purpose of this paper is to study and analyze the effect of the predominant risk influencing factors, primarily icing and low temperatures, which are caused by the unique Arctic operating condition, on the drilling waste handling practices. The paper specifies the interaction of the risk influencing factors, assesses the dependability of these factors on various variables, and evaluates their negative synergy effect on the drilling waste handling systems. Methods that could be possibly applied to manage the risks, for fulfilling the safe and sustainable Arctic drilling waste handling activities are discussed. Further, it presents a case study to assess risks related to the drilling waste management practices in the Barents Sea, Northern Norway. In the case-study risk assessments are performed, as well as preventive and mitigating means are identified.

Keywords: Arctic, Drilling waste, Icing, Low temperature, Risk, Waste handling

1. INTRODUCTION

Arctic offshore drilling waste handling practices are complex processes, involving unique system technology and design in a harsh environment and are vulnerable to system failures (AOOGG, 2014). Further, poor weather conditions and the relative lack of reliable weather forecasting, communication systems and other navigational aids pose challenges for the offshore drilling waste handling activities (IMO, 2010). Hence, effective management of potential hazards is an integral feature of safe waste handling operations in the Arctic offshore drilling (Salter and Ford, 2000). Robust waste management practices, especially in the Arctic offshore, requires understanding of the unique risks due to icing, ice loading, remoteness, very low temperatures, wind-chill effects, and etc., in addition to the 'conventional' or 'tolerable' risks.

Sea ice and atmospheric icing potentially lead to accretion of ice on the waste handling systems and structures (Battisti et al., 2006). The process of accretion of ice have significant impact on the performance of offshore waste handling system, the safety of personnel, and the overall economics of waste management operation (Gudmestad et al., 2007, Jacobsen and Gudmestad, 2012, Markeset, 2008, Barabadi and Markeset, 2011). The other overriding factor that must be accommodated in the analysis of the potential hazards in the cold Arctic regions is the prevailing low temperatures (Freitag and McFadden, 1997, Barabadi et al., 2009). Cold temperatures reduce the performance of components of the drilling waste handling system, ranging from primary shale shaker and mud cleaner to screw conveyor. In addition, for most drilling activity in the Arctic region, wells are recommended to be drilled with water-based drilling fluids (Det Norske Veritas, 2009, EniNorge, 2012). To meet the drilling-performance demands, thus the water must be kept from freezing or the system ceases to function. In worst case, the primary shale shaker, mud cleaner, screw conveyor, and the vacuum pump can be destroyed by the pressure of ice expansion. Furthermore, the viscosity of water increases significantly as temperature falls. Higher viscosity mean slower flow and mixing rates within the waste handling systems, and consequently increased the overall energy demand (Melton et al., 2004, Freitag and McFadden, 1997).

Hence, to addresses the above mentioned issues, proper analysis, identification, and understanding of the peculiar Arctic risks is vital step. Robust risk assessment can help to ensure that major risks are controlled to a level that is as low as reasonably practicable (ALARP) (Salter and Ford, 2000). To examine the potential hazards associated with offshore drilling and waste handling activities in the cold region, a number of safety and risk assessment models have been developed. For instance, Cohrssen and Covello (1999) proposed methods and principles for analyzing health and environmental risks from offshore drilling activities. To consider the effects of cold, Risikko et al. (2003) developed a model for managing cold-related health and safety risks at workplaces. For assessing environmental risk of the offshore drilling wastes, Sadiq and Husain (2005) suggested a fuzzy-based methodology. Qualitative risk assessment, systematic occupational health and safety management, and hazard identification are also discussed in different literatures (Lindøe et al., 2006, Broni-Bediako and Amorin, 2010, Ayele et al., 2015, Sadiq et al., 2004, Aven, 2008, Ryerson, 2009, Sadiq, 2001).

However, there is a lack of understanding of the impact of the predominant Arctic risk influencing factors, on the waste handling operation (AOOGG, 2014, Schmidt, 2012, Carson, 2013). Hence, the main purpose of this paper is to study and analyze the effect of the main risk influencing factors, primarily ice and low temperatures, on the chosen waste handling technology, while posed the following questions:

1. What are the distinctive Arctic operating environments and what are the peculiar Arctic risks?
2. How can operators minimize the most severe and unacceptable risks, with respect to HSE (health, safety, and environment)?

To answer these questions, the hazard identification and control measure selection processes through risk management and risk verification methods has been carried out. The rest of the paper is organized as follows: Section 2 discusses the predominant risk influencing factors in the Arctic region. Section 3 presents an illustrative case study. Section 4 investigates techniques for risk reduction and discusses methods for protecting the waste handling systems and structures against ice accretion. Section 5 provides the conclusion.

2. PREDOMINANT RISK INFLUENCING FACTORS

Risk influencing factors are factors that potentially affect the barriers and barrier performance (Aven, 2008). In general, in the Arctic region, environmental and climatic conditions are the predominant risk influencing factors. Some of the environmental and climatic conditions can be combined with each other and make new influencing factor. For instance, the low air temperature combines with wind speed to describe the wind-chill factor, which is the effect of these two parameters on exposed skin (Ayele et al., 2015). Table 1 illustrates the main risk influencing factors in the Arctic region. These factors were scored zero for the absence and one for presence of the factors during the drilling waste handling activity. The two key risk influencing factors – low temperature and icing, are discussed in brief.

Table 1: The occurrence of the predominant risk influencing factors in the Arctic region

Month	Snowstorm	Polar night	Icicles	Wind-chill effect	Icing		Negative Temperature		Polar lows
					Sea spray	Atmospheric	Sea	Air	
January	1	1	1	1	1	1	1	1	1
February	1	1	1	1	1	1	1	1	1
March	1	0	0	1	1	1	1	1	1
April	1	0	0	1	1	1	1	1	1
May	1	0	0	1	1	1	1	1	1
June	1	0	0	1	1	1	0	1	0
July	0	0	0	1	0	0	0	0	0
August	0	0	0	1	0	0	0	0	0
September	1	0	0	1	0	1	0	1	0
October	1	1	0	1	1	1	0	1	1
November	1	1	1	1	1	1	0	1	1
December	1	1	1	1	1	1	1	1	1

2.1. Low Temperatures

Low temperature can be categorized into two: negative air and sea temperature. The negative air temperature is the dominant factor that causes water to freeze. This leads to the stoppage of the overall waste handling process, and it also causes equipment damages. On the other side, the negative sea temperature signifies the occurrence of the sea ice as well as the icing phenomena as a result of sea spray. Generally, the effect of the low temperature on the waste handling activities has two facets. The first one is that, its effect on the waste handling system, such as increased equipment failures and energy consumption (for ships, cranes, trucks and earth-moving equipment at waste disposal sites) (Ayele et al., 2013). The second one is, its effect on the perfomance of the waste handling personnels. The performance of the waste handling personnel will significantly reduced due to cold hands, cold muscles or general cooling or due to hinders caused by protective clothing against cold such as weight, bulk, friction, etc (Ayele et al., 2015). Further, low temperatures causes reduced cognitive and reasoning abilities (i.e. cognitive errors are more likely to occur), significant reduction of the effectiveness of the workers, and possibility of mistakes or being inaccurate increases (Markeset, 2008).

2.2. Icing: Atmospheric and Sea Spray

Atmospheric icing can occur practically everywhere in the waste handling systems and can be categorized as: glaze, rime, frost, and sleet. Such kinds of atmospheric icing pose slipping hazards and other high-level occupational hazards such as permanent injuries. Further, they can cause the system to cease from functioning; and consequently they affect the waste handling activity significantly. On the other hand, sea spray icing occurs when the sea ice is in the limited extent and when there are favorable environmental factors such as strong winds and sea swells; and it is the main source of ice accretion on the stationary waste handling structures in the offshore drilling. Moreover, ships involving in the waste handling activities in the Arctic region can experience sea spray icing, which is considerably different from sea spray icing on the stationary waste handling structures. The reason is that, in case of the ship, the spray is generated as a result of heaving and pitching process as well as the interaction of the wave.

3. AN ILLUSTRATIVE CASE STUDY

A holistic risk assessment case study was carried out to assess risks related to the drilling waste management practices for an oilfield in the South Coast of Spitsbergen, Svalbard, Norway. The hypothetical oilfield is located in the Barents Sea – part of Norwegian Arctic, 85 km east of the southern coast of Spitsbergen, Svalbard. The scenarios of this case study are intended to be used for illustrative risk assessment purposes only and they are hypotheticals. The assessment of the predominant risks related to skip-and ship waste handling option, which is one of the main waste handling practices in the Arctic region, has been carried out. Skip and ship is the process of transporting the drilling waste to shore for further disposal procedure. In this process, cuttings are collected and transferred to a suitable location for loading within the drilling platform. Then, the drill waste is loaded (transferred) into skips via a steerable chute. Afterwards, full skips have to haul back to shore using a dedicated collection vessel or a standard platform supply vessel (PSV). The other option is to haul the waste back to shore using a closed system, for example, by means of bulk tanks.

3.1. On-site Risk Assessment

To evaluate the peculiar operational risks in the Arctic region and determine the performance of the skip-and ship waste handling systems, it is important to map the risks related to the susceptible areas. The first part of this risk assessment tries to identify the potential hazards within the defined susceptible areas for offshore drilling waste handling system. Figure 1 illustrates the schematic of the typical drilling waste handling systems deployed in the Arctic.

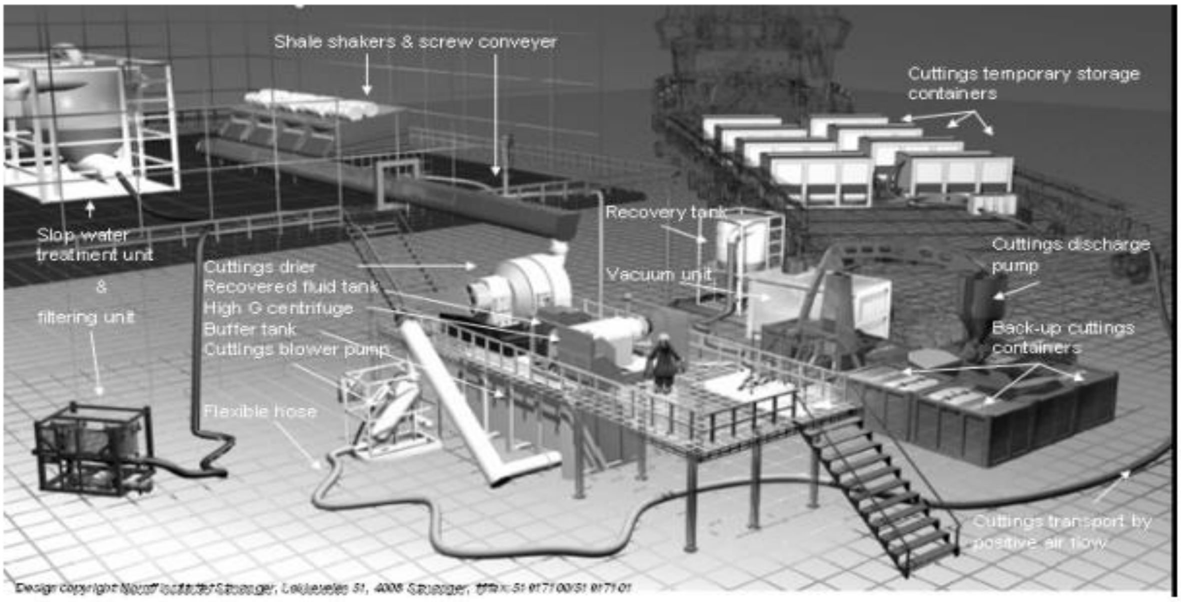

Figure 1: Typical waste handling technologies offshore drilling (Paulsen et al., 2005).

The main assumptions in this risk assessment are: a year-round operational window and there is no winterization or enclosure of the waste handling systems to protect the vulnerable areas. The likelihood and consequence of the potential hazards have been categorized into five levels, i.e. from level 1 to 5. Where level 5 indicates that the likelihood of occurrence is almost certain (i.e. expected to occur regularly under normal circumstances) and level 1 indicates rare probability of occurrence in a year (i.e. it could happen, but probably never will). Similarly, level 5 consequence category indicates that the potential hazard is associated with catastrophic damage; this can be damage to personnel, the environment, the equipment, and the reputation of the operator. Contrary, level 1 consequence category has negligible or insignificant damage. Table 2 illustrates the likelihood and consequence categories.

Table 2: Likelihood and Consequence categories

Category	**Description**	
	Likelihood	**Consequence**
1	Very unlikely, rare probability	Negligible, insignificant consequences
2	Unlikely, possible ice accretion but not likely	Slight, minor consequences
3	Possible, can occur during a year	Moderate, partly hinder the waste handling process
4	Likely, anticipated few times a year	Major, causes high or significant impact
5	Very likely, almost certain	Catastrophic, very high or severe damage

The most dominant operational, technological, and safety hazards associated with handling of drilling wastes in the cold Arctic environment are illustrated in Table 3. From the potential hazards assessment, it can be deduced that working in the cold Arctic environments has the potential if not managed properly to cause medium to high-level risks or an increase in incidences and injuries to the waste handling personnel as well as high-level equipment damages.

Table 3: On-site risk assessment

ID	**Hazard Susceptible Area**	**Hazard**	**Likelihood**		**Consequence**	
1	Shale shakers and screw conveyors.	Freezing temperature and ice accretion.	Likely to occur during winter period.	**4**	The system ceases to function; equipment damage as a result of ice expansion pressure; hinder maintenance process; and causes higher energy demand.	**5**
2	Storage containers, buffer and recovery tanks.	Atmospheric icing and negative air temperature.	Very likely to occur during winter period, and possible during summer.	**5**	Drilling cuttings being frozen stuck inside the container, this increases the need for holding tanks; and requirement for high-level operator intervention.	**3**
3	Vacuum unit.	Icicles, atmospheric icing, and negative air temperature.	Likely to occur during winter period.	**4**	Affects mud gravity and viscosity; reduced rate of mud circulation; and affects the cuttings recovery processes.	**3**
4	Filtering and slope water treatment unit.	Rime, glaze, snow, and icicles.	Expected to occur during the cold winter period.	**4**	Causes lower rate of mud/ slope water chemical utilization; reduces the effectiveness of the treatment of the contaminated mud/slope water; and increases operating and maintenance costs.	**3**
5	Cutting drier unit.	Negative air temperature, rime, glaze, and snow.	Expected during cold winter period.	**4**	Cutting build-up (frozen stuck) inside the recovery area and increases shutdowns for cleaning; difficulty to access and maintain	**4**

					the normal wear parts; and cause excessive erosion and component failure and higher maintenance cost.	
6	Centrifuges.	Atmospheric icing and negative air temperature.	Likely to occur during winter period, and possible during cold summer months.	**4**	Affects the inner flow speed; generation of vortex and agitating, which is a result of increased inside pressure; reduced fluid recovery rates and lower solids control efficiency.	**3**
7	Cutting blower pump.	Low temperature, rime, glaze, and snow.	Expected to occur during the cold winter period.	**4**	Ductility loss and pump failure; full stoppage of waste loading process; and can cause higher lead time.	**4**
8	Flexible hose.	Freezing temperature and ice accretion.	Probable to occur during winter period.	**3**	Partial or full stoppage of system, as a result of ice formation inside the hose; and hose failure damage as a result of ice expansion pressure.	**3**
9	Stairs, decks, railings, and catwalks.	Sea spray icing, rime, glaze, and snow.	Likely to occur during winter period, and possible during cold summer months.	**3**	Slipping hazard can cause fractures, bruises, lacerations, dislocations, as well as permanent injuries for personnel working at the waste handling site.	**3**

Table 4 demonstrates a two dimensional risk matrix that defines the level of the risk as a product of the likelihood of the potential hazards and consequences (negative outcomes). In the risk matrix, the green indicates – the low likelihood, low severity area – in this area the risk of unwanted events is not significant, or the planned barriers sufficiently reduces or controls the potential hazard. In such case no further action is required. The yellow indicates – the medium level risk category. For any unwanted event that falls within this area will be monitored and controlled by ALARP (as low as reasonably practicable) concept. Basically, the ALARP principle is, if we keep the risk at that level, we accept it. The red indicates – high likelihood, high severity area – here the risk of unwanted event requires rigorous risk control and reduction measures to bring the risk down to the ALARP level or to the green area.

Table 4: Risk matrix for typical offshore waste handling system

Likelihood						
	5			**2**		
	4			**3,4,6**	**5,7**	**1**
	3			**8,9**		
	2					
	1					
		1	2	3	4	5
		Consequence				

Categories
- Not Acceptable
- ALARP
- Acceptable

3.2. Logistical Chain Risk Assessment

The second part will analyze risks related to ships operating in the waste handling activities. As part of the logistical chain risk assessment, it is essential to estimate the expected ice-free navigation season in the South Coast of Spitsbergen. Figure 2 illustrates the mean ice concentration of the surrounding of the Svalbard archipelago, on a monthly basis for the years 2006 to 2010. Figure 2A and 2B shows the mean ice concentration for the month of March and August, respectively. The month of March, generally, is regarded as a high-ice concentration period of the year. Further, the region is ice free during the month of July, August, and September.

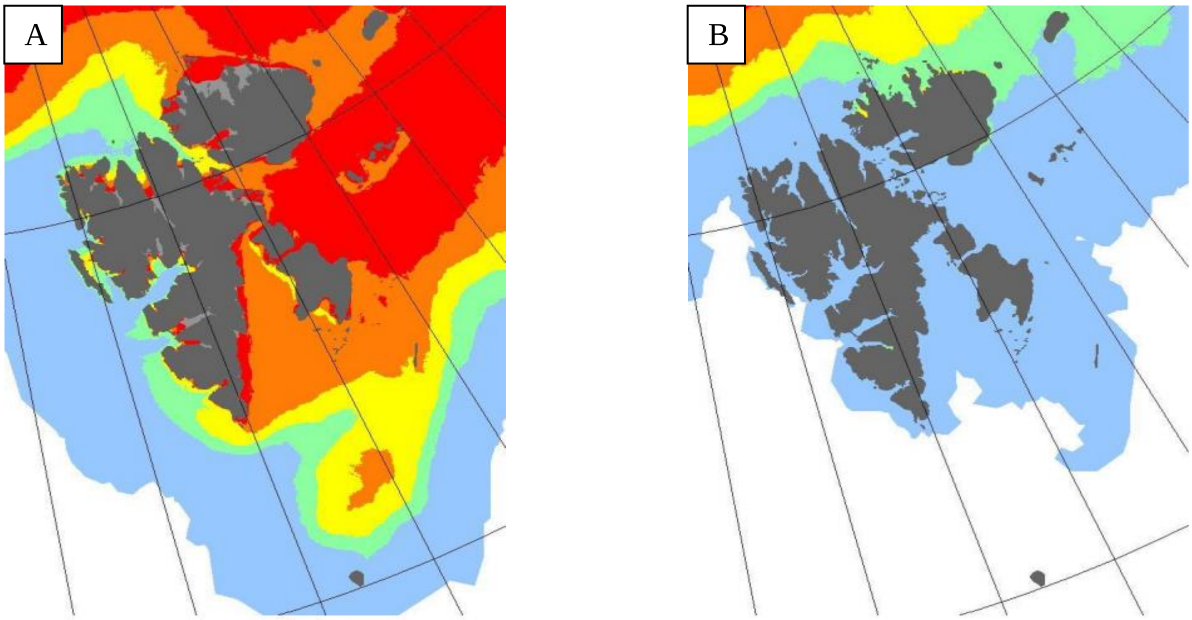

Figure 2: Mean ice concentration (A) for March 2006-2010 and (B) August 2006-2010
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A PSV (platform supply vessel) with ice class ICE-1A and De-ice notation have been considered, for the logistic of the drilling waste and year round operation in the eastern part of the South Coast of Spitsbergen. The considered vessel is assumed to be designed for extreme weather condition and cold water operations in the Barents Sea. The distance the ship must expect to sail in ice every month of the year (average conditions) on a route from the hypothetical oilfield to the Spitsbergen is summarized in Table 5. The expected maximum ice thickness in the surrounding of the Svalbard archipelago is assumed to be 1.30 m, which is based on the study carried out by Høyland (2009).

Table 5: The expected distance the PSV must expect to sail in ice every month of the year

Ice Type		
F	(grey)	Fast Ice
E	(red)	Very Close Drift Ice
D	(orange)	Close Drift Ice
C	(yellow)	Open Drift Ice
B	(green)	Very Open Drift Ice
A	(blue)	Open Water

	Offshore platform to Spitsbergen (46 NM)		
Operating Period	**Ice type**	**Ice thickness [m]**	**Total distance in ice [NM]**
January	B/C	< 1.30	**46** (20/26)
February	C/D/E	< 1.30	**46** (5/36/5)
March	D/E	< 1.30	**46** (40/6)
April	D/E	< 1.30	**46** (30/16)
May	D/E	< 1.30	**46** (36/10)
June	B	< 1.30	**10** (10)
July	Open Water	-	**-**
August	Open Water	-	**-**
September	Open Water	-	**-**
October	Open Water	-	**-**
November	B	< 1.30	**20** (20)
December	B/C	< 1.30	**46** (15/31)

Thus, from the mean ice concentration data analysis, the expected ice free operational window is estimated to be between 120 to 130 days, for the assumed PSV with ice class ICE-1A. That means for the rest of the season, the waste handling operator will face with demanding operating conditions. The possible limiting factors for PSV with ice class ICE-1A includes: higher fairways than those of ships of the lowest ice class; increased fuel costs since speed is reduced by even half on average due to ice barriers when proceeding in ice at full effect, and approaching the quay can take hours; higher harbor costs, since the basin must be kept open by a harbor tug in order for the vessels to reach the quay; increased heating requirement to keep equipment in working order despite outdoor temperatures; potential propulsion failure as a result of stuck in ice, crushing of hull or drifting aground; and black-out problem due to freezing of ship, crew, and difficult to restart.

To determine the consequence of the any failure mode or unwanted events, the generic event tree analysis (ETA) and the potential hazards identification and risk assessment has been carried. The generic Event Tree Analysis (ETA), in case of ice floe contact, during drilling waste transportation activities is illustrated in Figure 3. The ETA starts with an initiating event, in this case ice floe contact, and it assess the probabilities of several pivotal events and their respective outcomes. The worst negative outcome includes: oil and untreated drilling waste spill into the Sea, and consequently marine ecosystem damage. Further, the consequence of such kind of accident creates negative publicity, bad reputation or political risk for the PSV operator as well as the oil and gas industries operating in the region.

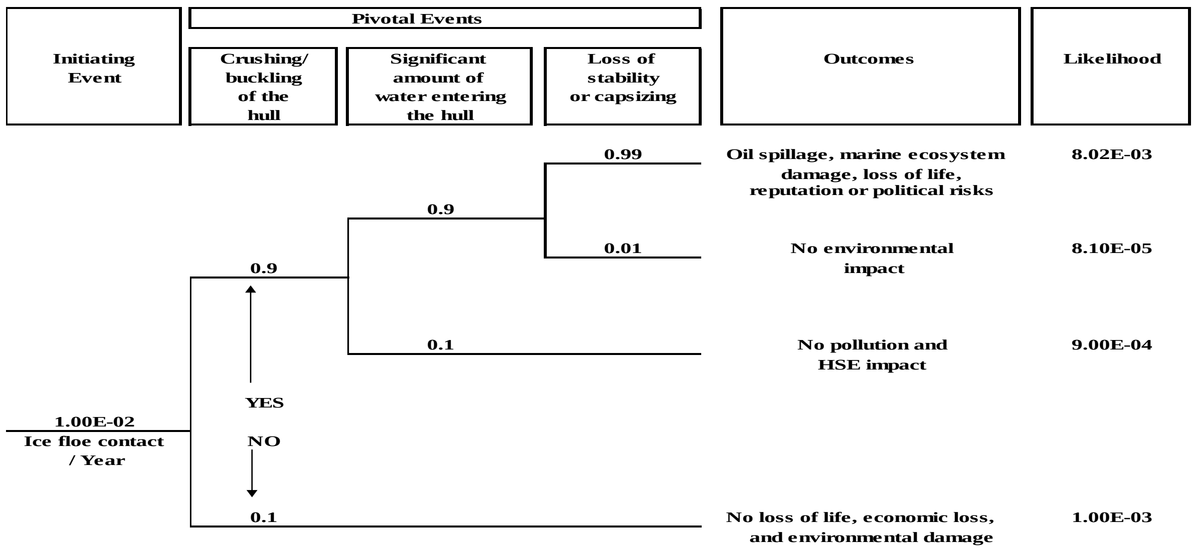

Figure 3: Generic Event Tree Analysis – Massive ice floe contact

A shortage of valid probability of occurrence data for the massive ice floe was a challenge during the event tree analysis. Since such data is critical to the decision making process, the absence of valid data can be a significant restriction to this technique. Further, to carry out the generic logistical chain risk assessment, categorization of the severity and consequence is essential. The standard severity and consequence categories, developed by Veritas (2001) and ABS (2000) has been applied during the logistical risk assessment. The hazards and potential consequences of unwanted events associated with offshore waste transportation in the Barents Sea are firstly identified and presented in a structured format in Table 6. The expected probability of occurrence of each event is then determined based on historical data and expert judgment. The expert judgment plays a very crucial role during offshore logistic risk analysis since one has less experience and data in the Arctic or Barents Sea (Ayele et al., 2014). With the expert judgment and the available information the consequence of the unwanted events has been analyzed to identify those risks, which need to be mitigated and to select the most appropriate risk-reduction approach.

Table 6: Logistical chain risk assessment

ID	Potential Hazard	Likelihood		Consequence	
1	Ice floes contact.	Very unlikely, but possible.	**1**	Capsizing /drifting aground; propulsion failure; oil and untreated drilling waste spill to the sea; HSE damage, several deaths; loss of vessel; serious marine incident; and significant economic loss.	**5**
2	Rime, glaze, snow, and icicles formation on the railings, decks, gangs, stairs and superstructure.	Very likely during winter period and possible during cold summer.	**5**	Personnel discomfort, sliding injury, minor occupational illness; equipment damages; increased energy consumption; and difficulty during maintenance operation.	**2**
3	Polar low accompanied by sea spray icing, and snowstorms.	Possible, can occur during winter.	**3**	Black-out as a result of freezing of the ship; loss of stability (in case of heavy load ice accretion in short time); personnel injuries; and increased heat requirement.	**5**
4	Negative air temperature and ice formation on windows, searchlights and navigation lights.	Likely to occur during winter, and probable in cold summer.	**3**	No indication of sailing direction, size of the ship, and no sign whether or not the ship anchored; reduced or no visibility for mariners; and possibility of collision.	**4**

Table 7 presents the product of the estimated logistical chain risks, as a two-dimensional risk matrix. The severity of capsizing or propulsion failure due to ice floe impact and black-out of the ship, as a result of sea spray icing are considered as significant; and need sufficient attention and priority.

Table 7: Risk matrix for logistical chain risk assessment

Likelihood						
	5		**2**			
	4					
	3				**4**	**3**
	2					
	1					**1**
		1	2	3	4	5
		Consequence				

Categories
- Not Acceptable
- ALARP
- Acceptable

4. RISK REDUCTION MEASURES (RRM's) – RISK AND ICE MANAGEMENT

The need to employ risk and ice management practices during the operational phase of an offshore waste handling activity is another important challenge in the Arctic region. The concept of risk management includes proper knowledge and understanding of the pro-active and re-active risk reduction measures. Typically, during waste handling activities, risk prevention or control measures can be implemented at the source level (e.g. elimination of the hazard, substitution, and redesign), along the path (e.g. during processing and transporting of the drilling waste), and at the worker (Ayele et al., 2015). On the other hand, ice management can be any method that protects the waste handling systems and structures against ice accretion, and it can also be a process of removal of the ice from the structure. Further, ice management measures, such as de-icing, anti-icing, and winterization (enclosure of the waste handling systems) helps to limit the accretion of the ice on the waste handling systems and remove the ice from the equipment's. For instance, the most common anti-icing measures are (Ryerson, 2009): coatings, design, heat, electrical, ice detection, and windows.

4.1. On-site Risk Assessment with RRM's

Winterization or enclosure of the waste handling systems, to protect vulnerable areas are considered as the main risk and ice incident impact reduction measure, for onsite risk assessment procedure. The winterization measures are very effective to reduce the likelihood or the probability of occurrence. However, their effectiveness is insignificant once the risk presents itself. Table 8 illustrates the risk reduction as a result of the application of the RRM's and shows that the risks from the potential hazards are all reduced to the ALARP and low-level risk categories.

Table 8: Risk matrix for offshore waste handling system (A) without RRM's (B) with RRM's

A

Likelihood	Consequence 1	2	3	4	5
5			**2**		
4			**3,4,6**	**5,7**	**1**
3			**8,9**		
2					
1					

B

Likelihood	Consequence 1	2	3	4	5
5					
4					
3					
2			**2,3**	**5**	
1			**4,6,8,9**	**7**	**1**

4.2. Logistical Chain Risk Assessment with RRM's

Table 9 presents the logistical chain risk assessment result (A) without RRM's (B) with RRM's. The assessment result shows that risk control and reduction measures were effective to bring the high-level risk categories risk down to the ALARP level or to the green area.

Table 9: Risk matrix for logistic chain (A) without RRM's (B) with RRM's

A

Likelihood	Consequence 1	2	3	4	5
5		**2**			
4					
3				**4**	**3**
2					
1					**1**

B

Likelihood	Consequence 1	2	3	4	5
5					
4					
3					
2		**2**		**4**	**3**
1					**1**

5. CONCLUSION

To smooth the expansion of the offshore industry into the hostile Arctic environment, risk-based approaches have a key role to play in ensuring the safety standards and regulation associated with handling and transporting of the drilling wastes. In this paper, the most dominant operational, technological, and safety hazards associated with handling and transporting of drilling wastes in the cold Arctic environment has been recognized. Further, the high-risk and low-risk susceptible areas have been clearly identified. Risk reductions as a result of the application of effective risk and ice management measures have been estimated.

The generic Event Tree Analysis (ETA) has been carried out, to investigate the worst negative outcome, while transporting the drilling wastes in the Barents Sea. The results from the case study, demonstrated that the arduous operating conditions of the Arctic, predominately low temperature and ice, have a compound negative effect on the system and performance of the waste handling personnel. To meet the stringent HSE requirement and reduce the risk, the explicit consideration of risk is therefore important. This will demonstrate the safety of the system and the overall waste handling practice in the cold Arctic region.

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