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OFFSHORE DRILLING RISK FILTERING, RANKING AND MANAGEMENT

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ABSTRACT

Managing offshore drilling risk typifies a problem of risk assessment and management of a complex system. We offer a framework to identify, assess, prioritize, and manage risks. It includes the following activities: (1) a holistic approach to risk identification; (2) prioritization of a large number of risks or risk scenarios; (3) structured solicitation and effective integration of expert judgment into qualitative and quantitative analyses to supplement limited data availability; (4) extreme and catastrophic event analysis; and (5) use of multi-objective framework to evaluate risk management options. From this analysis, decision makers will be able to identify deficiencies in the system's robustness, resiliency and redundancy, and decide on what measures to implement based on the trade-offs associated with each option.

Key words: Drilling Risk assessment; Risk influencing factors; Risk filtering & Ranking; Analytic Hierarchical Process: AHP; Risk matrix

INTRODUCTION

Jack-ups operate in large geographical regions and hence encounter various hazards. Each region poses its own particular threats. For instance, jack-ups may vulnerable to hurricanes in one region and be exposed to geohazards in another. However, there are other hazards, (e.g. corrosion, age degradation, poor maintenance), which equally affects every jack-ups. Identifying what can go wrong and their likelihood and possible consequences provides insight about vulnerability of the jack-up and helps to generate mitigation options. Filtering and Ranking risk contributors enable to decide priories and to focus on the most important risk contributors.

Drilling, like all complex activities, are exposed to a variety of hazards, some of which may be location and activity dependent; each of which may pose different risk. Also, the drilling risk management is a scalable activity and should be commensurate with the size, level of available information and complexity of the job. Furthermore, this process is iterative, since as the drilling communes, new information becomes available and some predicted events may occur while others will not, new hazardous events may occur or may be identified, and the characteristics of those already identified may change. Thus, an iterative risk management should be carried out at all stages of the life cycle. Consequently, the drilling risk management process has to be tailored for each particular case and stages of drilling.

There are usually more than six hazard groups influence the risk; also there may be several paths that each hazard could affect the risk. The main hazards groups are: Geohazards; Equipment & material; Human Elements; Local environment; Automation & human-Machine Interface; Design issues: Technology and Operation; Organizational elements; maintenance & Integrity; Externalities and so on. In some situations the age of the equipment and operation may also require particular attention. It is better not to have too many groups, thus minor threats should be grouped together, or with a similar group, to facilitate the assessment.

The proposed approach starts with structuring risks into a hierarchical system, which is a tree-like structure, consisting of two and more layers. The first level is the goal and the second level is all hazard groups. The identification of primary hazard groups is mainly based on engineering judgment and available data (accident databases). In the third level, each category is then broken down into several sub-categories. Each sub-category can be in turn broken into sub-sub-categories and so on (see Figure 2). This approach places hazards in a hierarchical structure as they are identified, and the structure is organized by source (category), consequently, the total risk exposure can be more easily understood, and planning for the risk more easily accomplished. This process produces a catalogue of all possible hazards, which must be filtered and hazards of lesser importance dropped from further studies.

The key elements of the framework are: (1) a hierarchy of major contributors to risk in two or more levels, which is also called the Risk Influencing Factors (RIFs). This hierarchical structure consist of goal, primary and secondary criteria (2) a quantification of primary scenarios by measurable attributes, (3) a graphical representation of risk to aide distinguishing critical hazards, (4) a layered filtering approach to remove less important hazards, (5) a weighted-score method, adapted from the analytic hierarchy process (AHP) (1 & 2).

SCENARIO IDENTIFICATION

In risk analysis we envision what could go wrong, how often and what are the consequences. Risk assessment is a process that must answer the following set of questions (3):

1. What can go wrong?
2. What is the likelihood?
3. What are the consequences?

As well as the following risk management questions:

1. What can be done?
2. What options are available?
3. What is the associated trade-offs in terms of all costs, benefits, and risks?

For this we need to list all possible events or "scenarios" as shown in Table 1. This table can be generalized as the following triplet (3):

$\langle S_i, L, C_i \rangle; \quad i = 1,2,\cdots,N$

Where

S_i is the scenario i

L_i is the likelihood of scenario i

C_i is the consequence of scenario i

It is also assumed that N are listed.

Scenarios	Frequency	Consequence
$\boldsymbol{S_1}$	L_1	C_1
$\boldsymbol{S_2}$	L_2	C_2
$\vdots$	$\vdots$	$\vdots$
$\boldsymbol{S_i}$	L_i	C_i
$\vdots$	$\vdots$	$\vdots$
$\boldsymbol{S_N}$	L_N	C_N

Table 1: Scenarios or events

If we managed to identify all scenarios (i.e. Table is complete), then we found the answer to the question posed and the risk is the total ensembles of triplet and denoted as (3):

$$R = \{\langle S_i, L_i, C_i \rangle\}$$

This equation is generally simplified as

$$R = \sum_{i}^{N} L_i \times C_i$$

The set of triplet should be complete, namely it should include every possible scenarios, or at least those which are important. In fact, it is not obvious how even near completeness can be achieved (4). Moreover, the set of scenarios must not overlap.

This approach generates a comprehensive list of all sources of hazards, i.e., categories of risks, commonly in the order of dozens of entries. Consequently, there is a need to discriminate among these sources as to their relevance, likelihood and severity. For this purpose, we propose a framework for risk filtering and ranking, based upon the following limitations:

- It is often impractical (e.g., due to time and resource constraints) to apply quantitative risk analysis to dozens of sources of risk. In such cases qualitative risk analysis may be adequate for decision purposes under certain conditions.
- All sources of evidence should be used in the filtering and ranking process to assess the significance of the risk sources. Such evidence items include engineering judgment, expert knowledge, statistical data, and common sense.
- To deploy the proposed framework effectively, we must consider all hazards, including those representing hardware, software, organizational, and human elements. Project risks (such as project cost overrun, loss of key personnel, and time delay in meeting completion schedules) and technical risks (such as not meeting performance criteria), are not considered in this paper.
- An integration of empirical and conceptual, descriptive and normative, quantitative and qualitative methods and approaches is always superior to the “either-or” choice (4). The trade-offs that are inherent in the risk management process manifest themselves in process. The multiple non-commensurate and often conflicting objectives that characterize most real systems guide the entire process of risk filtering and ranking (4)

The method offers a representation with the following advantages:

- A visual representation of all hazards, grouped in convenient categories, each category covering a series of event of similar concern. This helps to decide which must be carried forward for detailed study and get agreement from all stakeholders
- It can help to decide on the varying level of effort to eliminate, minimize and mitigate the consequence of residual risks commensurate with the level of information and the stage of the project
- It enables to communicate information to parties who will be tasked to deal with each risk category.
- Aggregation of risk and categories are transparent

Hazard identification is the first step in determining hazards affecting an activity. Identification also enable to documenting characteristics of hazards. Each hazard is a risk influencing factor. The best way to handle this is grouping them under heading s and subheadings. The heading assures that all hazards that might impact the drilling are identified during the hazard identification process. The sub-headings are attributes of each heading which facilitates the judgment process. Of course each sub-category can be in turn broken into sub-sub-categories and so on. Consequently, at least hazard categories (i.e. headings) are required for a minimum definition, but it could be as many levels as the analysts need to highlights all major hazards. This approach places hazards in a hierarchical structure as they are identified, and the structure is organized by source (category), consequently, the total risk exposure can be more easily understood, and planning for the risk more easily accomplished. Table 2 shows a two-level risk break down structure for offshore drilling. More remote hazards may be neglected and hence making the set of scenario incomplete.

Category	Sub-categories
C1-Geohazards	C11- Formation pressure C12 Soil & Rock types and strength C13- Shallow fault C14- Gas hydrate C15- Multiple Geohazards C16-Top-hole Geology
C-2Equipment & material	C21- Material suitability & defects; C22- Fabrication defects C23: Effect of Ageing; wear & tear or fatigued part; C24- Operational and resource limits C25- failure to meet qualification & code compliance C26- Late changes to well design and procedures; C27- Equipment quality (special equipment; delay; damaged C28 Spare & material availability,
C3- Human Elements	C31- skill & knowledge based mix C32- Workload & Work coordination; Shift and stint duration C33- Quality of working environment. C34- Communication C35- Performance evaluated & Suitability and Training; fit for the job
C5-Automation & human Machine Interface	C51- Software error C52- Temporary disabling safety devises C53- Information overload C54: Design of Human-machine interface C55 Failure of data processing function; failure of information support function; failure of surveillance function; Failure of communication function;
C6- Local environment	C61 Water depth C62 Local Weather C63 current & wave C64- Wind and water borne debris
C4- Design; Technology and Operation	C41- Technology Readiness maturity); C42- New technology (e.g. packers and liner hangers); C43-Down-hole monitoring; C44- Kick tolerance; C45 Deviation Vs hole size; C46Cementing of long casing strings; C47- Hole size contingencies; Well access and work over requirements; C48- Blow out contingency; C49- Well design and Job complexity
C7- Organisational elements	C71- Mix of cultures & compatibility (e.g. working to different procedures) C72- Organizational leaning C73- Personnel selection; Coordination C74- Training program, process and formalization C75- Safety commitment, perception & enforcement C76 Time and cost constraints C77- Bonus system and benefits upon performance

Table 2: The Risk Influencing Factors showing major risks and their attributes

This risk influencing structure can be viewed as a means leading to a set of actions or behaviour that are required of the system in order to succeed in functioning safely; conversely, each risk factor defines a scenarios in which the system fails to deliver in one or more actions. The union of all risk scenarios should then be complete. This completeness is a very desirable feature. However, the intersection of two of our risk scenario sets, corresponding to two different heading, may not be empty. The method allows the set of subsets to be overlapping.

Tables 2 lists major risk influencing factors reported in the literature. There are numerous Risk Influencing Factors (RIFs) which may influence a drilling operation, and there is a certain probability that only a number of RIFs to affect the risk. How strongly a RIF influences the risk is described by its weight relative to other RIFs.

RISK FILTERING

Generally, the number of RIFs is quite large. Clearly, not all of this sub-group can be of immediate concern. RIFs are filtered according to their likelihood and consequences if it were to occur. Filtering is achieved on the bases of expert experience and knowledge, function, and operation of the drilling system being assessed. This activity often substantially reduces the number of hazards. In this, the joint contributions of two different types of information-the likelihood of what can go wrong and the associated consequences-are estimated on the basis of the available evidence and engineering judgment.

Risk matrix is a useful tool for visualising risk. This type of tool is commonly used in combination with an expert based risk assessment. Since risk is defined as triplet then its likelihood and consequence must be judged. Knowing these, then each event is entered in a square of a matrix. The completed matrix shows which events are the risk drivers. We use the concept of likelihood and consequences to filter risks.

	$< 10^{-6}$/yr	10^{-5} to 10^{-6} /yr	10^{-4} to 10^{-5} /yr	10^{-3} to 10^{-4} /yr	10^{-2} to 10^{-3} /yr	10^{-1} to 10^{-2} /yr	1 to 10^{-1} /yr	> 1/yr			
	Catastrophic event	Extreme event	failure of the entire system	susbtaial systm failure	Partial failure	two or equipment fail	Equipment failure	Component Failure			
	RISK LEVELS										
	1	2	3	4	5	6	7	8	Consequenc Defintion		
Consequence Level Designation	A similar event has not yet occurred in our industry, but remotely possible	A similar event has not yet occurred in our industry, but it is possible	Similar event has occurred somewhere in our industry	Similar event has occurred somewhere within our company	Similar event has occurred, or is likely to occur, within the lifetime of similar facilities	Likely to occur once or twice in the facility lifetime	Event likely to occur several times in the facility lifetime	Common occurrence	**Safety Implication (Worst case)**	**Environmental Implication**	**Business loss**
A	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	>100 fatalities	-	>$20 bn
B	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	>50 fatalities	-	$5 bn - $20 bn
C	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	>10 fatalities	>20,000m3 condensate spill to sea	$1 bn - $5 bn
D	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	3 or more fatalities	10,000m3 condensate spill to sea	$100 m- $1 bn
E	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	1 or 2 fatalities	2000m3 condensate spill to sea	$5m -$100 m
F	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	1 or more DAFWC	100m3 spill to sea of condensate / MEG	$500k-$5m
G	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	1 or more recordable	1-10m3 spill to sea of condensate / MEG	$50k -$500k
H	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	First Aid	50litre spill to sea of condensate / MEG	<$50k

Figure 1: A typical industry risk matrix for filtering (and ranking) risks.

Commonly, 5x5 Matrix is used, but the 8x8 matrix (Figure 1) provided better resolution. Figure 1 defines eight scales and their linguistic description. Each risk scenario is characterized using qualitative assessment of both consequence and likelihood. In risk matrix, the likelihoods and consequences are combined into a joint concept called "severity" (3). The group of cells in the upper right indicates the highest level of severity. The mapping is achieved by first dividing the likelihood of a risk source into eight discrete ranges. Similarly, the consequence scale also is divided into eight ranges. The cells position determines the relative levels of severity.

In quantitative risk assessment, risk is defined as the product of likelihood of a hazards and its impact should it happen (3). The multiplication method could yield the same numerical value for a high consequence but low likelihood event to be the same as high likelihood but low consequence event. This is misleading picture, though both events are damaging, the high consequence event can wipe out an organisation. The problem is more pronounced for event in the middle of the risk matrix. Thus, boxes in Figure 1are numbered to indicate their position importance. This importance numbering gives more emphasis to the middle range, compare with the multiplication approach.

Each RIF from the catalogue is placed into a cell, according to its perceived likelihood and impact, to represents a class of failure scenarios. Each member of the class has its own combination of likelihood and consequence. Not all RIFs are of the same strength, or are of immediate and concurrent concern; hence these are filtered based on their severity and relevance. However, these risks can also be filtered based on scope, spatial & temporal domain considerations. Since we are considering the pipeline safety at the design stage, we start by presenting an initial set of relevant hazards which could be validated by all stakeholders. RIFs falling in the low-severity boxes are filtered out and set aside for later consideration.

RISK RANKING

The boundaries of the different levels of risks are not symmetrical, since a catastrophic event, irrespective of its probability, causes very large loss. The risk matrix doesn't provide a numerical relative importance of each rating, so the tool divides the risks in groups, but does not say anything about the ranking within such a group. Thus, after filtering minor hazards, the remaining hazards must be ranked to determine their relative strength. This enables to prioritise expenditure for avoiding, controlling and mitigating their impact.

There are two types of comparisons: absolute and relative. In absolute comparisons, two hazards are compared with a standard or a baseline which exists in one's mind and has been formed through experience. In relative comparisons, hazards are compared in pairs according to a common attribute. Saaty (1) proposed a pairwise comparison for determining the relative importance of two criteria known as analytic hierarchy process (AHP). The input to AHP models is the experts' answers to a series of questions of the general form, e.g. 'How important is criterion 'C1' relative to criterion 'C2'?' These are termed 'pairwise comparisons'. Within AHP, questions of this type may be used to establish, both weights for criteria and importance scores for different criteria, using a suitable scale (see the case example). Very often qualitative data cannot be known in terms of absolute values. AHP allows the integration of both, quantitative and qualitative criteria.

It is difficult to be completely consistent because of the complexity and diversity of subjective judgment. The AHP does not require that judgments to be totally consistent. But, priorities make sense only if derived from consistent or near consistent matrices, and hence consistency check must be applied. (1) Proposed a consistency index (CI) to measure the degree of consistency (or inconsistency) of the judgments for each stage of the AHP process. If the comparisons are not reasonably consistent, then this check provides a mechanism for improving consistency by going back to the pairwise comparison. The mathematical background is given in the Appendix.

EXAMPLE CASE

The ranking process is illustrated using an example case, which is a segment of a transportation pipeline passing through a seismically active area. Consider an onshore long distance transmission pipeline. An efficient way of evaluating risk is to divide this pipeline into segments; these are areas whose risks are evidently different from its neighbours and identifiable by well-defined boundaries. After filtering less important RIFs, the remaining RIFs must be ranked to understand their contribution to the overall risks.

In a hazard filtering process, it was determined that the categories that have the largest direct effect on the risk are as listed in the first column of Table 3. Hazard group 7 in this table is a mixture of hazard group 7 and 8 of Table 1, combined for the presentation purposes. The rest of hazards listed in Tables 1 and 2 are considered either not to apply or to be of no importance and hence were filtered out. The first five categories equally apply to all pipeline segments, and the last category is route dependent. Figure 2 shows the content of Table 3 in its hierarchal structure. Some of RIFs are time dependent (for instance, corrosion) while some are time independent e.g. the internal pressure; or just for one time, e.g. installation.

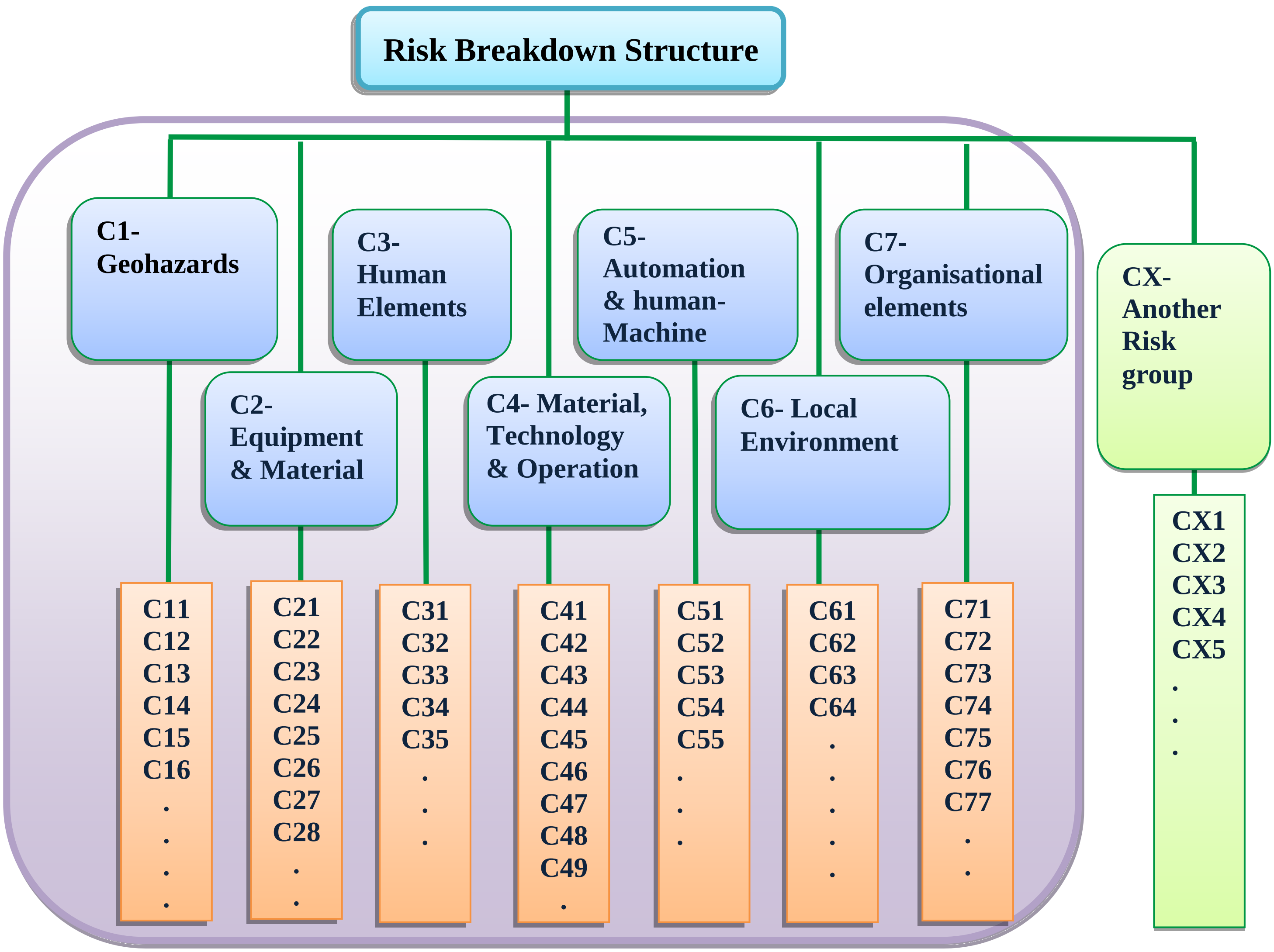

Figure 2: Risk Breakdown Structure for the case example

In consultation with the industry experts seven pairwise comparison matrices were developed to determine the criteria and sub-criteria weights. The weights for all the pairwise comparison matrices were computed using a spreadsheet. By aggregating the hierarchy, the preferential weight of each criterion is found. A consistency check is then performed. If the comparisons are not reasonably consistent, then this check provides a mechanism for improving consistency by going back to the pairwise comparison.

Primary Criteria	Weight/Primary	Sub-criteria	weight/sub	Combined weight
C1-Geohazards	0.20	C11	0.213	0.043
		C12	0.343	0.069
		C13	0.153	0.031
		C14	0.146	0.030
		C15	0.073	0.015
		C16	0.073	0.015
C-2 Equipment & material	0.17	C21	0.228	0.040
		C22	0.125	0.022
		C23	0.039	0.007
		C24	0.218	0.038
		C25	0.098	0.017
		C26	0.098	0.017
		C27	0.098	0.017
		C28	0.098	0.017
C3- Human Elements	0.19	C31	0.183	0.034
		C32	0.212	0.040
		C33	0.195	0.037
		C34	0.196	0.037
		C35	0.213	0.040
C4- Design; Technology and Operation	0.16	C41	0.028	0.005
		C42	0.026	0.004
		C43	0.058	0.009
		C44	0.053	0.009
		C45	0.115	0.019
		C46	0.180	0.029
		C47	0.180	0.029
		C48	0.180	0.029
		C49	0.180	0.029
C5-Automation & human-Machine Interface	0.12	C51	0.147	0.017
		C52	0.107	0.013
		C53	0.285	0.033
		C54	0.261	0.030
		C55	0.199	0.023
C6- Local environment	0.11	C61	0.151	0.017
		C62	0.201	0.022
		C63	0.367	0.041
		C64	0.281	0.031
C7- Organisational elements	0.05	C71	0.215	0.010
		C72	0.247	0.012
		C73	0.148	0.007
		C74	0.077	0.004
		C75	0.115	0.005
		C76	0.090	0.004
		C77	0.106	0.005

Table 3: Summary of pairwise comparison matrices

Figure 3 shows the pairwise comparison of the primary groups (the second level). Each column is summed up first, and then each element is divided by the sum of its column. The weight is then averaged of each row, as shown Figure 2. Figures 4 to 10 are the pairwise comparison matrices for all subcategories.

	C1	C2	C3	C4	C5	C6	C7	Weight
C1	1	2	1	1	1	2	6	0.20
C2	1/2	1	1/2	2	2	1	6	0.17
C3	1	1	1	1	2	3	2	0.19
C4	1	1/2	1	1	2	2	2	0.16
C5	1	1/2	1/2	1/2	1	1	4	0.12
C6	1/2	1	1/3	1/3	1	1	5	0.11
C7	1/6	1/6	1/2	1/2	1/4	1/5	1	0.05
Sum	6 1/6	4 5/6	6 1/3	9 1/4	10 1/5	26	6 1/6	1.00
CR= 0.0589								

Figure 3: First level pairwise comparison matrix

	C11	C22	C13	C14	C15	C16	Weight
C11	**1**	2	1	1	2	2	0.213
C12	1	**1**	2	3	6	6	0.343
C13	1	1/2	**1**	1	2	2	0.153
C14	1	1/3	1	**1**	2	2	0.146
C15	0.5	1/6	1/2	0.5	**1**	1	0.073
C16	0.5	1/6	1/2	0.5	**1**	1	0.073
Sum	5	4 1/6	6	7	14	14	1.000
CR=0.089							

Figure4: Pairwise comparison for Geohazards group

	C21	C22	C23	C24	C25	C26	C27	C28	Weight
C22	1	1	5	1	3	3	3	3	0.228
C22	1	1	2	1	1	1	1	1	0.125
C23	1/5	1/2	1	1/3	1/4	1/4	1/4	1/4	0.039
C24	1	1	3	1	3	3	3	3	0.218
C25	1/3	1	4	1/3	1	1	1	1	0.098
C26	1/3	1	4	1/3	1	1	1	1	0.098
C27	1/3	1	4	1/3	1	1	1	1	0.098
C28	1/3	1	4	1/3	1	1	1	1	0.098
Sum	4 1/2	7 1/2	27	4 2/3	11 1/4	11 1/4	11 1/4	11 1/4	1.000
CR=0.081									

Figure 5: Praise for Equipment & material group

	C31	C32	C33	C34	C35	Weight
C31	1	7/8	1 1/4	4/5	4/5	0.183
C32	1 1/7	1	5/6	1 1/4	1 1/4	0.212
C33	4/5	1 2/9	1	1	1	0.195
C34	1 1/4	4/5	1	1	1	0.196
C35	1 1/4	1 1/4	1	1	1	0.213
Sum	5 4/9	5 1/7	5	5	5	1.000
CR=0.0329						

Figure 6: Praise comparison for Human Elements group

	C41	C42	C43	C44	C45	C46	C47	C48	C49	Weight
C41	1	1	1/3	1/3	1/5	1/5	1/5	1/5	1/5	0.027973
C42	1	1	1/7	1/5	1/7	1/5	1/5	1/5	1/5	0.0259277
C43	3	7	1	1	1/3	1/5	1/5	1/5	1/5	0.0582558
C44	3	5	1	1	1/3	1/5	1/5	1/5	1/5	0.0528358
C45	5	7	3	3	1	1/2	1/2	1/2	1/2	0.1149734
C46	5	5	5	5	2	1	1	1	1	0.1800086
C47	5	5	5	5	2	1	1	1	1	0.1800086
C48	5	5	5	5	2	1	1	1	1	0.1800086
C49	5	5	5	5	2	1	1	1	1	0.1800086
Sum	33	41	25 1/2	25 1/2	10	5 2/7	5 2/7	5 2/7	5 2/7	1
CR= 0.0745										

Figure 7: Pairwise comparison Design; Technology and Operation group

	C51	C52	C53	C54	C55	Weight
C51	1	2	1/3	1/2	1	0.1474301
C52	1/2	1	2/5	1/4	1	0.1071122
C53	3	2 1/2	1	1	1 1/3	0.2854275
C54	2	4	1	1	2/3	0.2606656
C55	1	1	3/4	1 1/2	1	0.1993647
Sum	7 1/2	10 1/2	3 1/2	4 1/4	5	1
CR=0.0925						

Figure 8: Pairwise comparison for Automation & human-Machine Interface group

	C61	C62	C63	C64	Weight
C61	1	1	1/3	1/2	0.1508403
C62	1	1	1/2	1	0.2012605
C63	3	2	1	1	0.3668067
C64	2	1	1	1	0.2810924
Sum	7	5	2 5/6	3 1/2	1
CR= 0.0320					

Figure 7: Pairwise comparison for Local environment group

	C71	C72	C73	C74	C75	C76	C77	Weight
C71	1	2	2	2	1 1/2	1 1/2	1 1/2	0.215
C72	1/2	1	2	3	3	3	3	0.247
C73	1/2	1/2	1	1	2	2	2	0.148
C74	1/2	1/3	1	1	1/2	1/2	1/2	0.077
C75	2/3	1/3	1	2	1	1	1	0.115
C76	2/3	1/3	1/2	2		1	1	0.090
C77	2/3	1/3	1/2	2	1	1	1	0.106
Sum	4 1/2	4 5/6	8	13	9	10	10	1.000
CR= 0.0535								

Figure 8: Pairwise comparison for Organisational elements group

Table 3 summarizes these results. The second column gives the ranking of the top level categories as calculated in Figure 4. The fourth column give the ranking of all hazards within each category, which taken from Figure 4 to 10. The last column is the multiplication of the second and the fourth columns. These results are plotted in Figure 11 and 12, respectively.

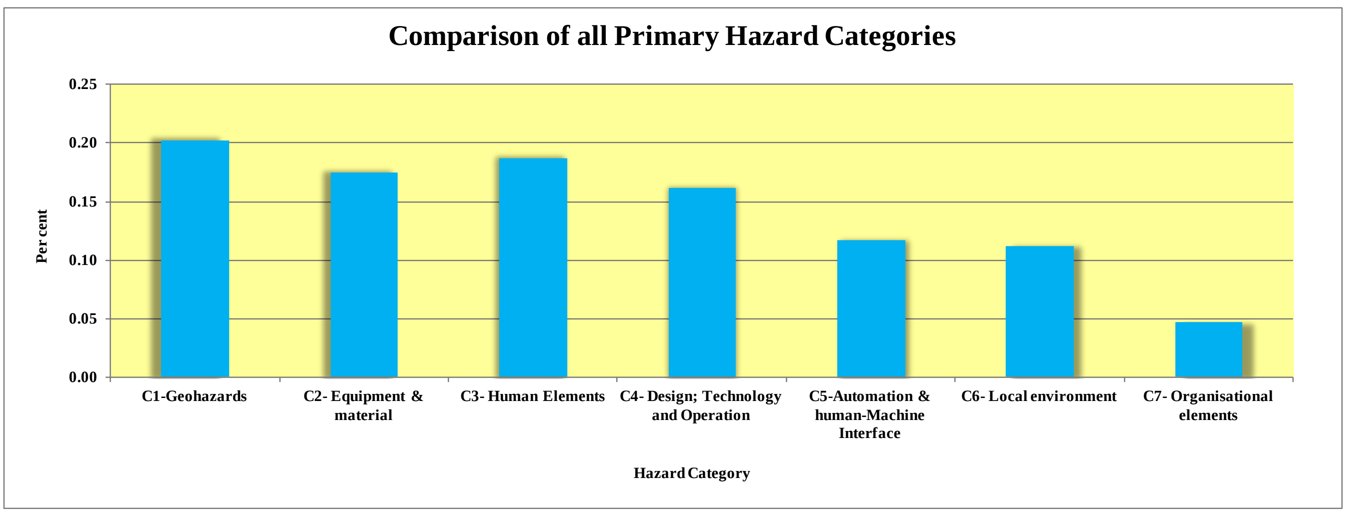

Figure 9: Ranking of the top level risks

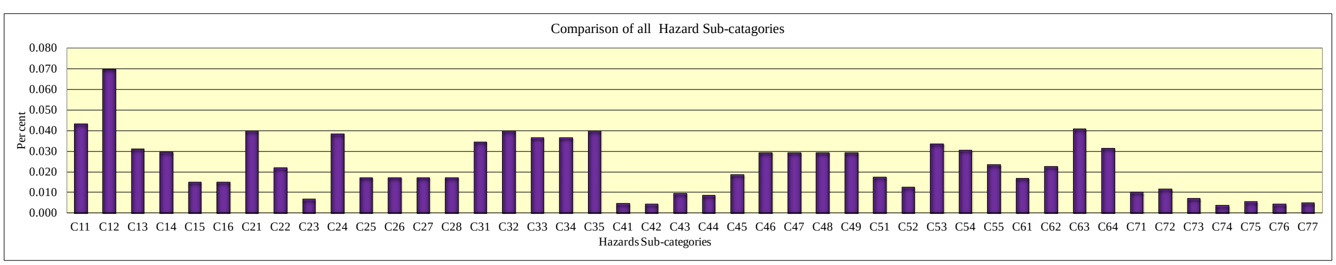

Figure 10: Ranking of all hazard sub-categories to risk.

RISK MANGMENT

The concept of safety barrier is used to manage drilling risk. The safety barrier approach is based on two models, the Swiss cheese accident model (Figure 11) and the bow tie method (Figure 12). Imagine a row of Swiss cheese slices in which each slice is a barrier and the hole represents a weakness in the barrier that may fail to stop an event. If the holes line up, which may occur when multiple barriers are not in place or properly functioning, accidents can occur- the more barriers, the safer the facility, and the smaller the holes, the smaller the weaknesses in the barrier.

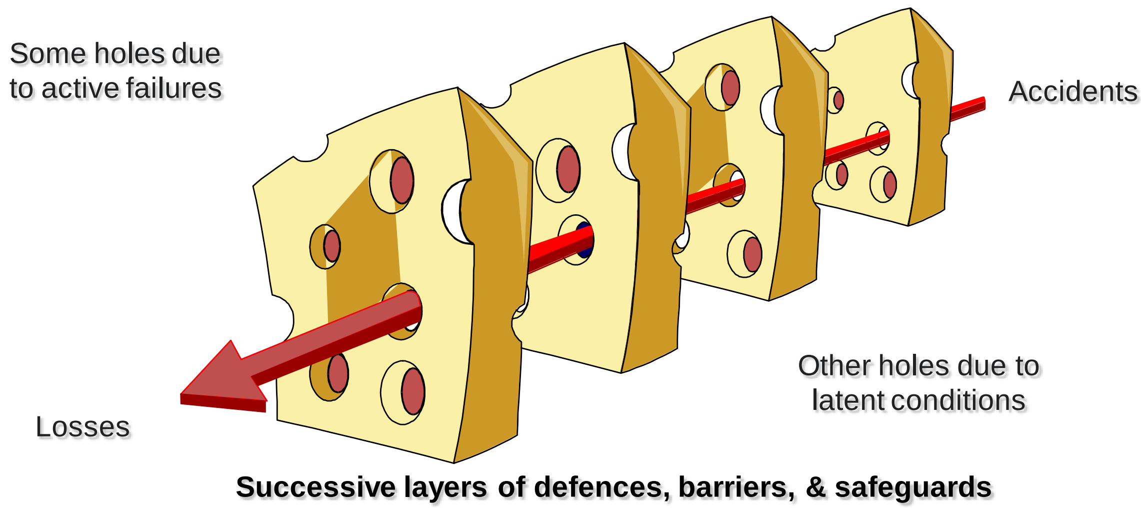

Figure 11: James Reason's Swiss cheese model

The tool that captures the Swiss cheese concept and carries it further is the Bow Tie Diagram (Figure 12). For each "Top Event", such as a major leak, blowout, or explosion, all of the threats, such as corrosion, equipment malfunctions or failure to follow operating procedures are shown on the left, while the effects, such as asset or environmental damage are shown on the right. The prevention barriers are then between the threats and the top event, while the mitigation barriers are between the top event and the outcome.

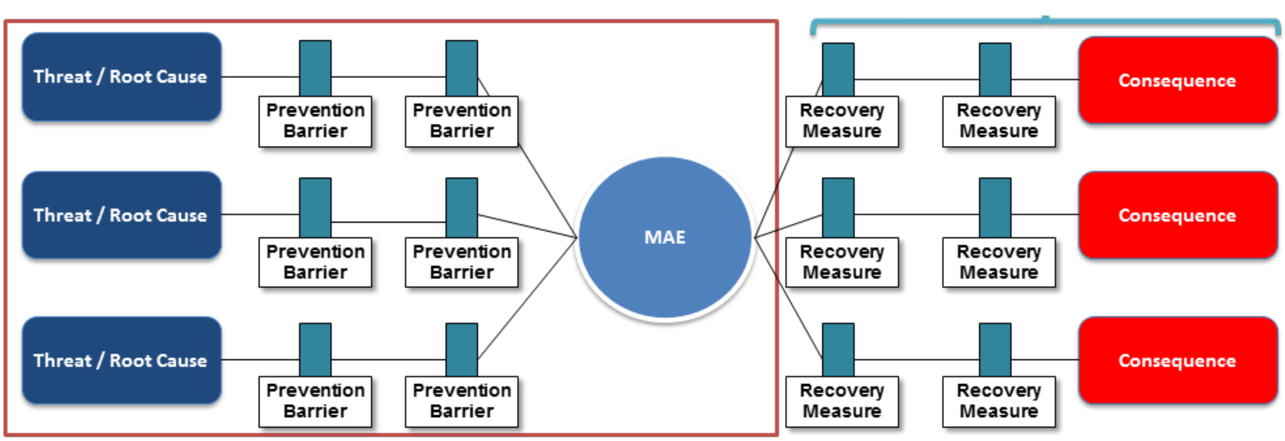

Figure 12: Bow-tie model

Barrier management was developed specifically to meet operational risk management needs. Usually, there are 2–5 barriers in each pathway leading to and from the top event. Barriers can be a specific control, such as a hardware item, a technical or automation feature, a management system or an administrative procedure. In effective barrier management systems, each barrier is monitored by operating personnel, its status is known at all times, and additional information on each barrier is available, such as the owner responsible for the barrier control, cross-references to specific procedures or maintenance plans, or minimum performance standards for the barrier.

Conventional well-control strategies include casing, fluid programs, and other barriers to well control incidents in the well design and BOP, and other mitigation procedures that help minimize the impact of an incident should one occur. The primary barrier is the hydrostatic pressure of mud which is larger than of the pore pressure. In underbalance drilling, this barrier must be adjusted. In this case it is composed of the drilling fluid column and a separate back pressure choke.

The secondary barrier is the envelope consisting of the blowout preventer, the casing, the exposed wellbore below the casing shoe and the drill string. If the primary barrier is failed, this barrier is closed.

CONCLUSIONS

Measuring risks is essential to reduce exposure, and it can be used for other purposes such as upgrading an existing jack-up for life extension, change of use, reducing corporate risk exposure or measuring cost effectiveness of expenditures. The prosed approach is an effective tool for such purposes. The purpose of risk analysis is to obtain robust design. Risk analysis identifies all factors which influences a design. Robust Design is an engineering methodology that aims at reducing the performance variation of a system by choosing and setting of its control factors to make it less sensitive to variable variation.

We used the risk matrix to filtering risks and AHP to rank the remaining risk by eliciting opinion of several experts. Opinions of several experts can be aggregated after going through the process described above and then averaging the calculated ranks. Such averaging may be done before processing the data. Using fuzzy mathematics is also proposed for aggregation, but their value is uncertain as AHP itself is dealing with fuzzy situation and it is doubtful if further complication would ass value. There are other methods for aggregation (6) which involves more calculations.

The AHP is a versatile decision aid which can handle problems involving both multiple objectives and uncertainty. It is popular with many decision makers who find the questions it poses easy to answer. It should, however, not be forgotten that the purpose of any decision aid is to provide insights and understanding, rather than to prescribe a “correct” solution. Often the process of attempting to structure the problem is more useful in achieving these aims than the numeric output of the model.

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APPENDIX

Generally, AHP follows these steps:

1. Define the problem and determine its goal.
2. Structure the hierarchy from the top (the goal) through intermediate levels (criteria on which subsequent levels depend) to the lowest level, which typically contains a list of alternatives.
3. Employ a pair-wise comparison approach. Saaty (16) developed the fundamental scale for pair-wise comparisons. The elements in the second level are arranged into a matrix and judgments about the relative importance of the elements with respect to the overall goal are selected.

Scale	Definition	Explanation
1	Equal important	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Very strong importance	An activity is strongly favour and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed
Reciprocal- if activity i has one of the above numbers assigned to it when compared with RIF j, then j has the reciprocal value when compared with i.		

Table 1- The Fundamental Scale

When the elements being compared are closer together than indicated by the scale, one can use the scale 1.1, 1.2, ..., 1.9. If still finer, one can use the appropriate percentage refinement [Saaty (16)].
The pair-wise comparison matrix A, in which the element a_{ij} of the matrix is the relative importance of the i^{th} factor with respect to the j^{th} factor, could be calculated as

$$A = [a_{ij}] = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \end{array} \qquad (1)$$

4. There are $n(n-1)/2$ judgments required developing the set of matrices in step 3. Reciprocals are automatically assigned to each pair-wise comparison, where n is the matrix size.
6. A reciprocal value is assigned to the inverse comparison; that is, $a_{ij} = 1/a_{ji}$ where $a_{ij}(a_{ji})$ represents the importance weight of the ith(jth) element. Once the pairwise comparisons are completed, the local priority vector $w$is computed as the unique solution to $A \times w = \lambda_{max}\, w$ where A is the matrix of pairwise comparison, w is the eigenvector and λ_{max} is the largest eigenvalue of A.
In addition to eigenvalue method, there are several other algorithms available for approximating the vector w (Saaty, 1988). We use a two-stage algorithm for averaging normalised columns and approximating the vector w.

$w_i = \left(\sum_{j=1}^{n}\left(a_{ij}/\sum_{i=1}^{n} a_{ij}\right)\right)/n$ for $i = 1, \dots, n$. (2)

7. Consistency test. Each pair-wise comparison contains numerous decision elements for the consistency index (CI), which measures the entire consistency judgment for each comparison matrix and the hierarchy structure. Saaty (16) utilized the CI and consistency ration (CR) to assess the consistency of the comparison matrix. The CI and CR are defined as

$CI = \frac{\lambda_{max} - n}{n-1}$ CI= $\frac{\lambda \max - n}{n-1}$ (3)

where n is the matrix size.

$CR = \frac{CI}{RI}$ (4)

The consistency can be checked by taking the CR of CI with the appropriate value (Table 1). The *CR* is acceptable if it does not exceed 0.10. The CR is > 0.10, the judgment matrix is inconsistent. To acquire a consistent matrix, judgments should be reviewed and improved.

Table 2- Average random consistency (RI).

Size of Matrix, n	1	2	3	4	5	6	7	8	9	10
Random Consistency Index, RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

The AHP allows inconsistency, but provides a measure of the inconsistency in each set of judgments. This measure is an important by-product of the process of deriving priorities based on pair-wise comparisons.